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DIE CASTING

BY

H. H. DOEHLER
Chairman of the Board, Doehler-Jarvis Corporation

FIRST EDITION

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DIE CASTING

PREFACE

It is a fundamental fact that quantity production of quality goods has been the underlying reason why the people of America have achieved a standard of living far above that of other countries and previous civilizations. No one production technique can be singled out as *the* one that made such progress possible. Any method that has shortened the time necessary to convert raw material into a finished part has had some effect, the degree depending upon how fast, how accurate, and how practical that technique has proved to be. As one of the fastest and most practical production methods, die casting has made—and still is making—significant contributions to industrial progress.

No one other fabricating technique has contributed more to the economic and quantity production of metal parts. Wherever one may look—in the office, store, or factory, on the street, or in the home—he is confronted with numerous products in which die castings are an integral part. The automobile and other means for transportation on the street, the vacuum sweeper and other household devices in the home, and the various types of business machines in the office, store, and factory are but a few of the many end uses of die-cast parts. Aircraft, precision instruments, hardware, industrial machinery, internal-combustion engines, and thousands of other items depend upon the production of die-cast components. From an obscure beginning, die casting has grown into a mighty industry. And instead of leveling off, production rates are still steadily increasing.

When a process reaches such a high state of perfection, there is a tendency for some to think of future progress in terms of "refinements." Such thinking is always fallacious, and especially so when applied to die castings. Too many things remain to be done: the development of satisfactory die materials for high-melting-point alloys, for one. Bigger and better casting machines, improved finishing techniques, casting of metals that have not yet been practical, and increases in size and intricacy of die-cast parts are but a few of the others.

In so far as applications are concerned, the so-called limitations of the die-casting process are nonexistent. They exist only in the minds of those who do not fully appreciate the potentials of this method of production.

The purpose of this book is to make such individuals—whether they be students, production engineers, or product designers—fully aware of these possibilities by discussing, in so far as is practical, the present-day production methods and design techniques and by pointing out probable trends in the near future.

The contents of this book are in reality a compilation of the combined knowledge of metallurgists, chemists, engineers, die- and toolmakers, electroplaters, technicians, and specialists of the Doehler-Jarvis Corporation. The author gratefully acknowledges the extraordinary efforts of those who have contributed. A special meritorious mention is due to J. C. Fox, under whose supervision the various texts were guided and assembled. The conception of the idea of this book and its purposes is to be credited to Charles Pack. The author also wishes to acknowledge the invaluable assistance rendered by V. H. Laughner for his editing and arranging of the text.

H. H. DOEHLER

NEW YORK, N. Y.
January, 1951

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INTRODUCTION

One of the oldest methods of casting molten metal is by gravity pouring into sand molds. That method, with many refinements, is still practiced in our present so-called "sand foundries." In the course of time, the jewelry trade by its requirements for sharper outlines and smoother castings developed a process utilizing plaster—or gypsum—molds. This method resulted in parts having a finer surface finish than sand castings, but the disadvantage was that, as in sand casting, the mold had to be destroyed to remove the cast part.

The search for a permanent mold or form which could be used to produce parts in quantity from the same mold seemed to be a natural evolution. In the Middle Ages the pewterware manufacturers perfected a casting process using iron molds to produce plates, cups, pitchers, and other household utensils. Our museums display many pewter products of beautiful designs. The next step was the production of toy soldiers, or so-called "tin soldiers," which appeared in the 1800's. They were made by the gravity pouring of molten metal in iron molds, constructed in two halves, which were hinged together and mechanically opened and closed. At about the same time the slush-mold process became a factor in producing hollow castings such as figures and toys. It consisted of pouring molten lead alloy in an iron mold and emptying the unchilled inner metal after the surface was sufficiently chilled.

In the light of those established practices of using iron molds for quantity production from a permanent mold and to produce sharper, better, and smoother cast parts, in contrast to the centuries-old method of using sand forms, the next logical step was to improve accuracy and appearance of cast parts further by applying pressure to force the molten metal into strong steel molds, instead of merely relying on gravity pressure.

Manually operated machines such as those patented by Sturges in 1849, Barr in 1852, Pelize in 1856, Dusenbury in 1877, and others, all had for their ultimate goal the rapid casting of type. This eventually led to the development of the linotype machine by Ottmar Mergenthaler. In this machine a number of metallic forms or matrices were assembled automatically, and a line of type the width of a newspaper column was cast. The metal was forced into the mold by means of a piston and a cylinder immersed in liquid metal. At the start of the century, the author patented a die-casting machine that is now on display at the

Smithsonian Institution in Washington, D.C.; that machine embodied the principle of the first Mergenthaler linotype machine in that it had a submerged plunger and a pump to force molten metal into a mold.

Since the early die-casting experimenter thus started out with the knowledge disclosed by the linotype machine, the first commercial die castings, mainly for such items as automotive bearings, were produced from tin- and lead-base alloys. It was soon evident that if the process were to become an important factor in metal fabrication, it would have to be made adaptable to other and more useful alloys having better mechanical properties and higher fusion points. It was quickly learned, however, that the problems connected with the casting of these alloys multiplied as the melting point of the alloys increased.

Zinc-base alloys, having a slightly higher melting point than tin and lead but possessing superior mechanical properties, were tried next. By constant improvement in the casting mechanisms and techniques, and by the use of better alloys, zinc-base-alloy die castings were finally advanced to a point where they became a vital factor in modern engineering processing (see Chap. 7, Die-casting Alloys).

The first commercial aluminum-base-alloy die castings were produced by the Doehler Die Casting Company in 1915. During World War I, the process was sufficiently developed to be utilized in the manufacture of gas-mask parts, machine-gun components, binoculars, and many other parts which greatly furthered the war program. Today, the aluminum die-casting process is indispensable in the metalworking art.

Magnesium also is an important member in the family of commercial metals, and metallurgical developments of the past 10 years have placed this metal on a favorable competitive basis with aluminum. The die-casting process, keeping abreast of metallurgical development, has been extended to the use of this metal. There is no doubt that magnesium die castings will continue to find an ever-increasing field of application in engineering practice.

Aluminum and magnesium alloys both have melting points in the vicinity of 1200°F. In the order of their melting points, the next useful range of alloys are the so-called "brasses," or copper-zinc alloys. The melting points of these alloys range from 1600°F upward. Although a difference of 400°F may not seem particularly large, the difficulties encountered in die casting pyramid rapidly as the melting point increases, and the casting of metal under pressure at temperatures of around 1700°F in steel molds presents many problems that still have not been entirely solved. Nevertheless, the brass die-casting process is in commercial operation and an appreciable tonnage of brass is being die-cast, the volume increasing steadily. Special brass alloys have been developed that

have a tensile strength of over 100,000 psi—the strength of some heat-treated alloy steels.

Much progress has also been made in die-casting techniques during the past four decades. The control of casting variables, such as metal and die temperatures, pressures, and shot speeds, is much advanced. Considerable improvement has been made in the evolution from the first manually operated plunger-type die-casting machine, which required the work of three or four men to operate, to the present, practically automatic plunger machine, which requires only one man to control and which performs 300 to 500 casting cycles per hr. Steels for dies have been refined to the stage at which economical die life is obtained with all the die-casting alloys, and rapid strides are being made in perfecting even more suitable die materials.

REQUIREMENTS FOR SUCCESSFUL DIE CASTING

At this point it is obvious that there are many requirements which must be satisfied before the production of sound, economical die castings can be assured. Of these, three are of primary importance:

1. A smoothly working casting mechanism, properly designed to hold and operate a die under pressure
2. A properly designed and constructed die
3. A suitable alloy

All three of these factors must be considered together—not individually. Good castings cannot be produced if one of them is not up to standard. For instance, if a perfectly designed and constructed die is mounted on a well-operating casting machine, a poor die casting will result if the alloy is inferior or not in accordance with standard specifications. Similarly, good castings cannot be produced from a perfectly balanced alloy if either the die or the machine is not up to standard.

The successful production of die casting also requires, in some cases, the setup of low-cost, high-production, gang-machining equipment; facilities for mechanical, chemical, or organic or metallic finishing of the castings; facilities for rapid but accurate inspection, both during and following the casting, machining, and finishing operations; and last, but not least, a staff of trained engineers, metallurgists, and technicians to effect the coordination of all factors. Parts must first be suitably designed before they can be produced as die castings; dies must be properly designed and constructed; and alloys must be designated to meet the service requirements of the part and must be carefully prepared and rigidly controlled within the limits set by standard specifications.

The Machine. The function of a die-casting machine is to hold the two halves of the die tightly together; to inject molten metal under pressure into the die cavity; and to close and open the die halves to permit removal of the finished casting.

The die, which consists of two steel blocks into which an impression of the casting is cut, plus cores and other component parts, is mounted on the casting-machine frame. When the machine is closed, the two halves of the die are locked tightly together, after which the molten metal is injected at high speed and under high pressure into the cavity through gates in the die. The die halves are fastened to opposing plates, which are in perfect alignment in the machine frame, and the other moving parts of the die are so designed that they can be operated in proper sequence as the machine opens or closes.

Essentially, any die-casting machine consists of (1) a frame on which the die and actuating equipment are mounted; (2) the actuating device, which opens and closes the die and which, in almost all modern machines, is a hydraulic cylinder and piston arrangement or a hydraulic cylinder and toggle arrangement; and (3) the injection or front end of the machine, which forces the molten metal into the die under pressure.

The frame and back end of the machine are fundamentally the same, regardless of the type. It is the front end that differs and accounts for the two basic classifications in the industry today: the "submerged-plunger" machine (Fig. 1), which is used for casting tin, lead, and zinc; and the "cold-chamber" machine (Fig. 2), which is used for die-casting aluminum, magnesium, and copper parts. The furnace that holds the metal at casting temperature is not an integral part of the latter type. The metal is ladled, either manually or automatically, into the injection cylinder prior to each shot; from there, it is forced by a hydraulically actuated plunger into the die. On the submerged-plunger machine, the furnace is actually attached to the front end, and the plunger and cylinder are submerged in the molten metal. At the end of each shot, metal flows into the cylinder; and at the start of the next cycle, it is forced by the plunger into the die.

One reason that the higher melting point alloys of copper, aluminum, and magnesium cannot be cast in a submerged-plunger machine is that the steel or cast-iron surface of the plunger and cylinder, being submerged in the furnace at all times, contaminates the alloy and thus causes the production of inferior castings. This alloy contamination does not occur in a cold-chamber machine, first because the alloy is in contact with the plunger and cylinder for only a short period of time, and secondly because these components are usually kept relatively cool.

Injection pressures are extremely high, which accounts for the trend toward hydraulically actuated, instead of mechanically actuated, machines. Total pressures of 10,000 psi and higher are not uncommon, depending somewhat on the size and type of machine and its locking

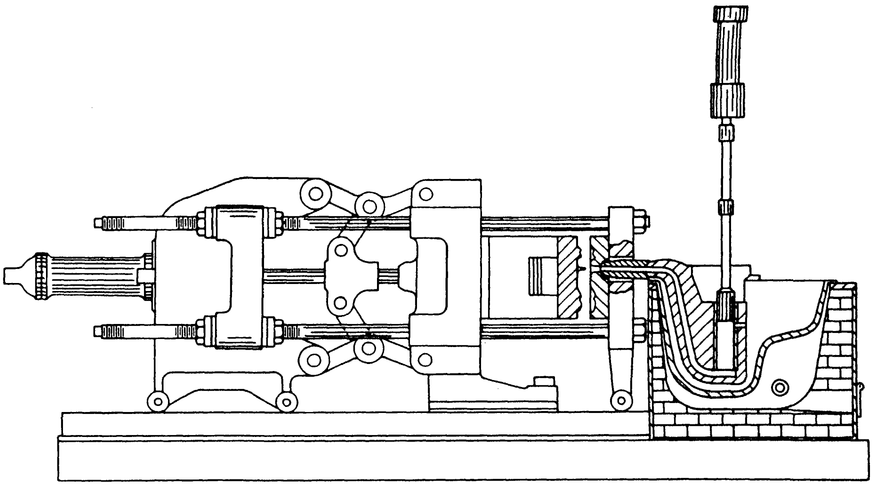


FIG. 1. Principal components of a submerged-plunger machine for die casting of tin, lead, and zinc alloys.

pressure, *i.e.*, the force available to hold the two halves of the die together when the shot is being made. Injection pressures of this magnitude ensure that the molten metal will be forced into small and remote sections

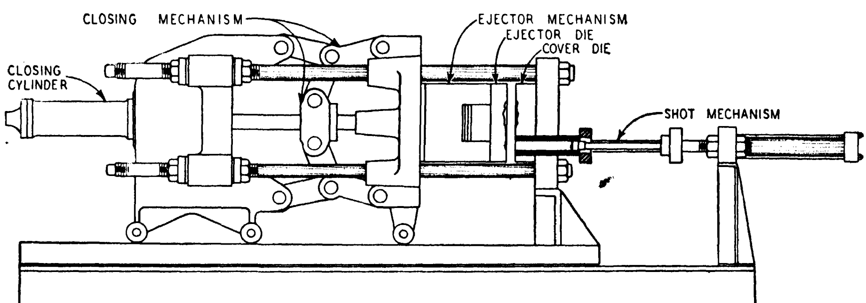


FIG. 2. Principal components of a cold-chamber machine for die casting of aluminum, magnesium, and copper-base alloys.

of the die before it can "freeze" and that the casting will be of high density and free of porosity—other conditions being satisfactory.

Most die-casting machines are designed in such a manner that the speed or cycle for making the "shot" to produce the casting is of as short

duration as possible. The operator usually starts the cycle by pushing a button and removes the casting, which is ejected from the cavity by automatic or manual means, as the machine is opened. Although this sequence sounds quite simple, the machine is exceedingly complex.

The Die. A simple die-casting die consists of two blocks of steel (Fig. 3), each containing a part of the casting impression. These blocks are mounted on a machine and are so arranged that one is stationary (the

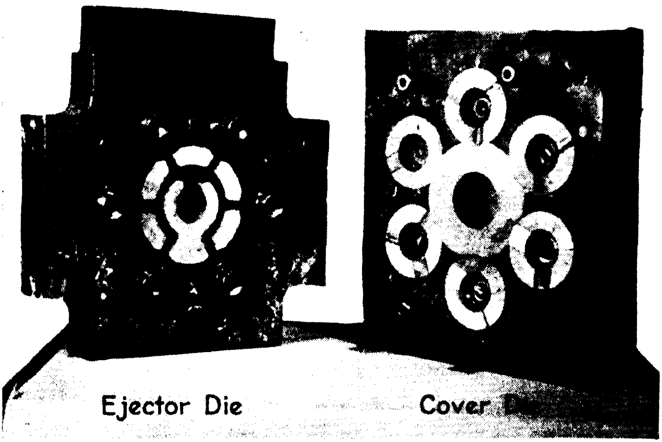


FIG. 3. A die-casting die is made of two blocks of steel into which the impression of the part is machined or hobbed. The two halves are held in alignment by dowels when the machine is closed to make the shot. Shown is a multiple-impression die for casting six parts simultaneously.

cover die) while the other is movable (the ejector die). The meeting surfaces of the die blocks are finished so that they fit together; the blocks are locked together prior to injecting the molten metal and drawn apart to allow the removal of the casting. Since the two halves must remain in exact register upon opening until the full depth of the casting is free from the cover half of the die, they are held in alignment by dowel pins.

Proper means for rapidly ejecting the casting from the die must be provided. This is usually accomplished by means of ejector pins (Fig. 4), which are mounted in an ejector plate and assembled to the die base (Fig. 5). It is the task of the die designer to place these ejector pins in such a position on the casting that they eject the casting from the die without distortion and in such a manner that the ejector-pin marks on the casting are not objectionable. One fundamental requirement for ease of removal is to have the casting remain in the ejector-die half.

Thus, the movable or ejector block usually contains, in addition to part of the casting impression, all movable elements such as cores, slides, and ejector mechanisms.

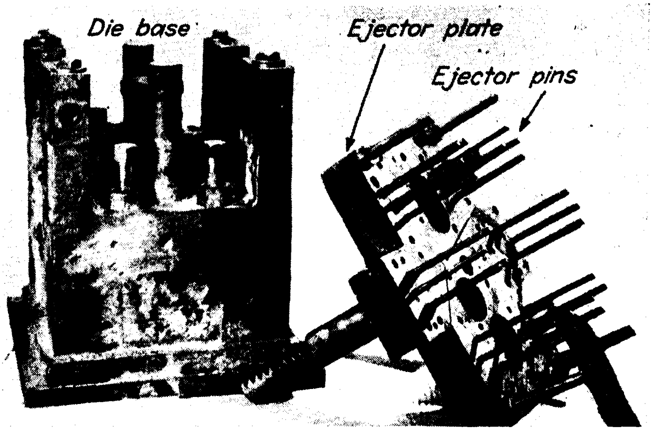


FIG. 4. The casting usually is ejected from the die by means of ejector pins that push the casting out of the ejector half of the die after the die is opened.

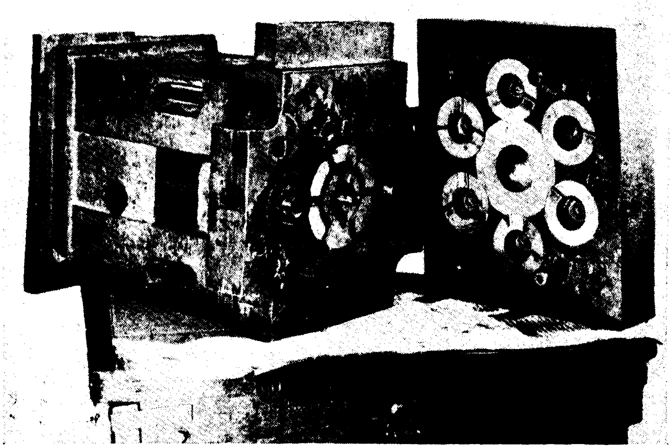


FIG. 5. Assembly of the die components shown in the previous two illustrations. This assembly then is mounted on the casting machine.

The orifice in the die through which the molten metal flows to fill the casting impressions is known as the "gate" or "metal inlet." When two or more impressions are in the same die, feeder lines must branch out from the main gate to each impression. These lines are usually termed

"gate runners." The location of the gate is of vital importance, as are its dimensions in relation to the area of the casting.

Vents, ranging in depth from 0.006 to 0.015 in. are incorporated in the die to allow air that is displaced by the molten metal to escape from the *die impression. Failure to provide suitable venting may result in un-*sound castings. Many methods of venting are available, and the die designer must determine the method and the extent of venting required from the size, contour, and section of the casting.

Finally, many other die features may be desirable or necessary under certain circumstances. Sliding cores, loose die pieces, actuating means for cores, inserted casting impressions, water-cooling lines, and other components often must be added to obtain sound, economical castings.

Of course, the material of which the die is made governs to a large extent the commercial success of the die-casting process. First of all, since the metal is forced into the die under high pressure, the die material must be capable of withstanding high impact and mechanical shock. Secondly, the casting alloy is injected at high temperatures, so the die must be capable of withstanding high thermal shocks as well. The combination of these two characteristics, plus others such as resistance to erosion, a low coefficient of thermal expansion, and dimensional stability during heat-treatment, means that the die must be constructed of the highest quality alloy steel and that the die components must be of correspondingly high quality. With the lower melting point alloys—tin, lead, and zinc—the problem of securing a long die life at an economical cost is not so acute. With the higher melting point alloys, however, the steel must be of the best possible grade and must be alloyed, poured, cropped, and forged to rigid specifications.

The Alloy. Die castings are made of six principal base alloys: tin, lead, zinc, copper, aluminum, and magnesium. Of these, zinc, aluminum, and magnesium, in that order, account for the major tonnage. Zinc is used for many structural parts in the automotive, electric-appliance, and business-machine industries because of its low cost, ease of casting, and ability to take a good finish; most of the chromium-plated parts on a modern automobile are zinc die castings. Aluminum is increasing rapidly in popularity (Figs. 6 and 7), due in large part to a decreasing price trend in the cost of the raw material; it is light in weight, has better dimensional stability than zinc, is a good electrical conductor, and has good corrosion resistance. Magnesium is used primarily because of its light weight.

The composition of each of these alloys must be held within prescribed limits or the required physical and mechanical properties will not be achieved in the finished part. Standard base die-casting alloys, described

in specifications of the American Society for Testing Materials, are used by most die-casting manufacturers. Aluminum and magnesium compositions are also bought by metal-supplier designation—Alcoa or Dowmetal, for example. In addition, some large die casters have set up their own standards for casting alloys. However, none of the alloys vary much in composition between suppliers.

FIG. 6. Frames, bases, and other structural parts for household mixers that are made by die casting. The motor of the electric motor used to drive the mixer also usually is an aluminum die casting.

The melting and alloying department of a modern die-casting plant is most important, since it is the starting point of die-casting production. Just as the casting plant is dependent for production on a steady supply of water, gas, and electricity, it is also and to the same degree dependent upon a constant supply of suitable alloy. Failure of supply of any one of these items means complete shutdown in the production of a plant. The steady supply to the casting department of clean metal of the proper composition and temperature, in the required quantity, and at minimum

costs is mandatory for good, efficient casting production. It is for this reason that melting and alloying practices and policies, when once established, should be rigidly followed in order to eliminate the variables arising from any divergence in the quality of the metal emanating from the melting department.

FIG. 7. Die-cast members for cameras, projectors, viewers, and miscellaneous photographic equipment. Note the complex shapes and intricate detail that can be obtained.

The first step in the quality control of metals is to purchase metals in strict accordance with definite specifications, which in turn are based on standard specifications. The metals must be purchased from reliable suppliers and the purchasing confined to as few of these suppliers as possible without jeopardizing the assurance of an adequate supply of metal at all times. The fewer the suppliers, the less the variation in quality arising from different smelting practices. All shipments of metal received must be carefully sampled so that complete chemical analyses

can be made on all heats making up a shipment. Those heats which do not meet the purchasing specifications should be subject to segregation and possible rejection.

The ingots, slabs, bars, or other forms in which the metal is received should be examined for excessive shrinkage, cracks, roughness, and oxidation, and for the general condition of the surface. Heats that contain ingots showing excessive shrinkage cavities and cracks are evidence of the metal being poured at excessively high temperatures; those showing roughness or sandy finish indicate segregation or improper fluxing before pouring; and those showing excessive oxidation may indicate improper storage.

MECHANICAL ENGINEERING AND METALLURGY

From the foregoing discussion it is apparent that the factors affecting the production of sound, economical die castings are almost infinite in number. A detailed discussion of these factors plus specific data on all the aspects of the die-casting process constitute the remaining chapters of this book. The chapters on the casting machine, the die, the part design, and the practical aspects of the die-casting process might be considered as comprising the "mechanical" section; those on the alloys, the die steels, and finishing might be considered as falling under the broad term of "metallurgy"; and those on trimming, machining, and inspection really fall into the "auxiliary operations" category—important, but not in the strict sense a part of the die-casting operation.

CHAPTER 1

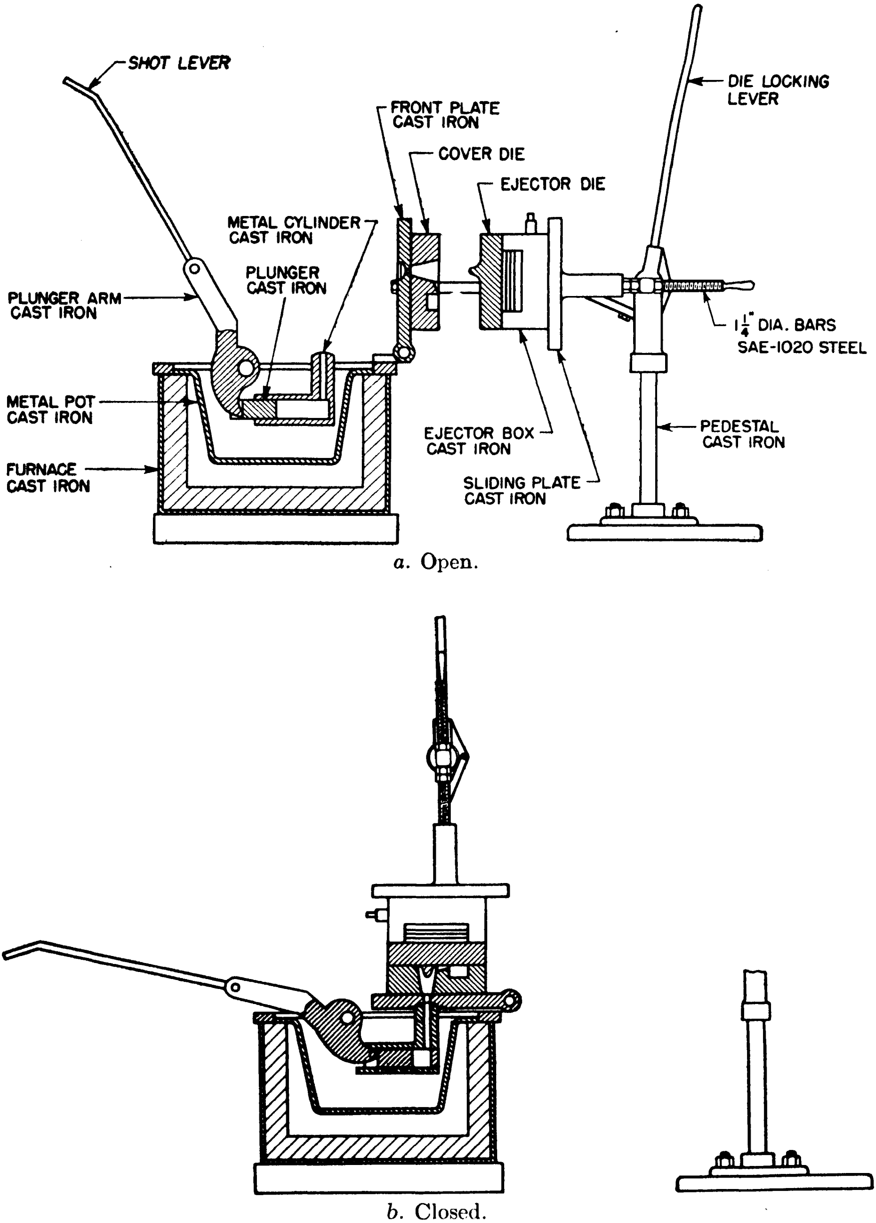
DIE-CASTING MACHINES

The development of the die-casting machine followed along two distinctly different channels: the *plunger-* and the *air-operated* machines. The former is the principle embodied in the Mergenthaler linotype machine, in which the metal is forced into the die by means of a plunger and cylinder immersed in the molten metal. In the air machine, as its name indicates, the metal is displaced or forced in the die by means of compressed air. Both types of machine were used in the development of the die-casting process and both are still in use today, although the air machine is the least efficient and is rapidly becoming obsolete.

The Plunger Machine. One of the first commercially successful die-casting machines was patented by the author in 1905 and used by the Doehler Die Casting Company during its early history. It is described here mainly for its historical interest and to indicate the progress that has been made in this type of casting machine to date when compared with the latest type of plunger machine.

The casting principle of this machine, which is shown in the open position in Fig. 1.1*a* is as follows: A cast-iron holding pot is set into the furnace. A cylinder mounted in this holding pot is submerged in the molten metal. A plunger is adapted to move laterally in this cylinder by means of a plunger arm that is actuated by a force applied to the shot lever. The metal fills the cylinder, by gravity, through an aperture provided for that purpose. When a force is applied to the lever, the plunger arm pivots around the fulcrum pin, causing the plunger to move forward in the cylinder. The forward movement of the plunger first closes the filling port and then forces the metal contained in the cylinder out of the cylinder outlet.

The two die members are suitably mounted on platens that are held together by two bars. The platens or frame is opened and closed by manual power applied to the die-locking lever. After the die is locked, the entire die and frame is then swung manually to the vertical position shown in Fig. 1.1*b*, pivoting on the swivel joint. This brings the die gate in contact with the filling nozzle; and manual power is then applied to the lever that moves the plunger forward and forces the metal into the die cavity.



a. Open.

b. Closed.

FIG. 1.1. One of the first plunger-type die-casting machines that was used for commercial production. It was manually operated and limited to the casting of zinc, tin, and lead alloys.

In the actual operation of the machine, two men were required to operate the frame and to "swing" it 90 deg. For small castings, one man was required to "pull" the lever or make the shot. Large and complicated castings required two "pullers." Crude as this machine may seem today, it was typical of its time and was used quite successfully in the production of magneto housings, carburetors, and other automotive parts during the early days of the automotive industry and until about 1915.

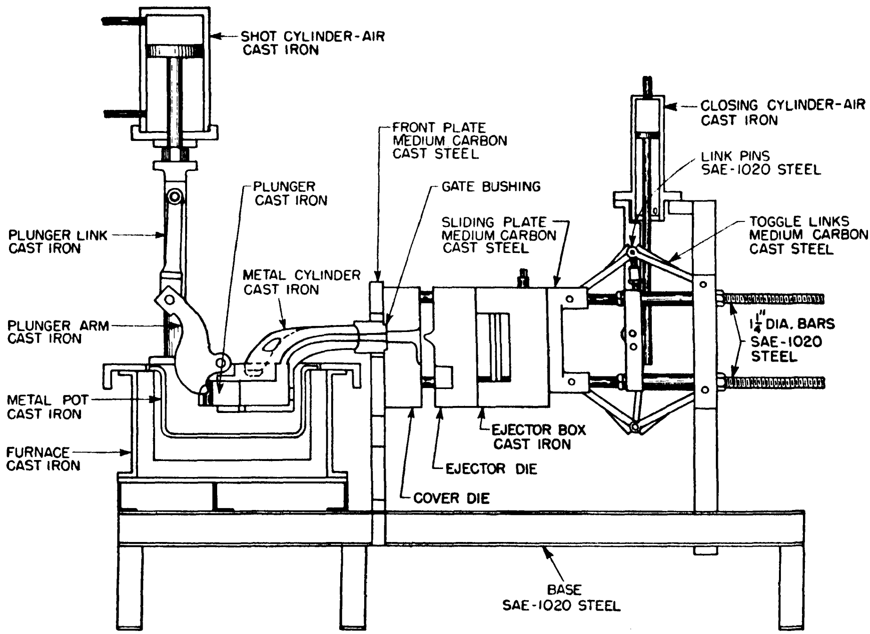


FIG. 1.2. Improved version of the original machine. It utilized pneumatic pressure to force the metal into the die and had the frame and the die in a fixed plane.

However, since the operation of this first machine required the services of three or four men, it was soon found untenable, and the next step was a reduction in the manual labor required to operate it. The first improvement was made by eliminating the pullers and utilizing pneumatic pressure for forcing the metal into the die. The next improvement was to build a machine wherein the frame and the die could be operated in a constant plane (Fig. 1.2) instead of in planes 90 deg apart. These changes were forced on the industry by the increasing size and weight of dies required for the production of increasingly larger die castings. The substitution of pneumatic for manual power reduced fatigue, thus enabling the operator to produce more uniform castings, and made higher injection pressures possible.

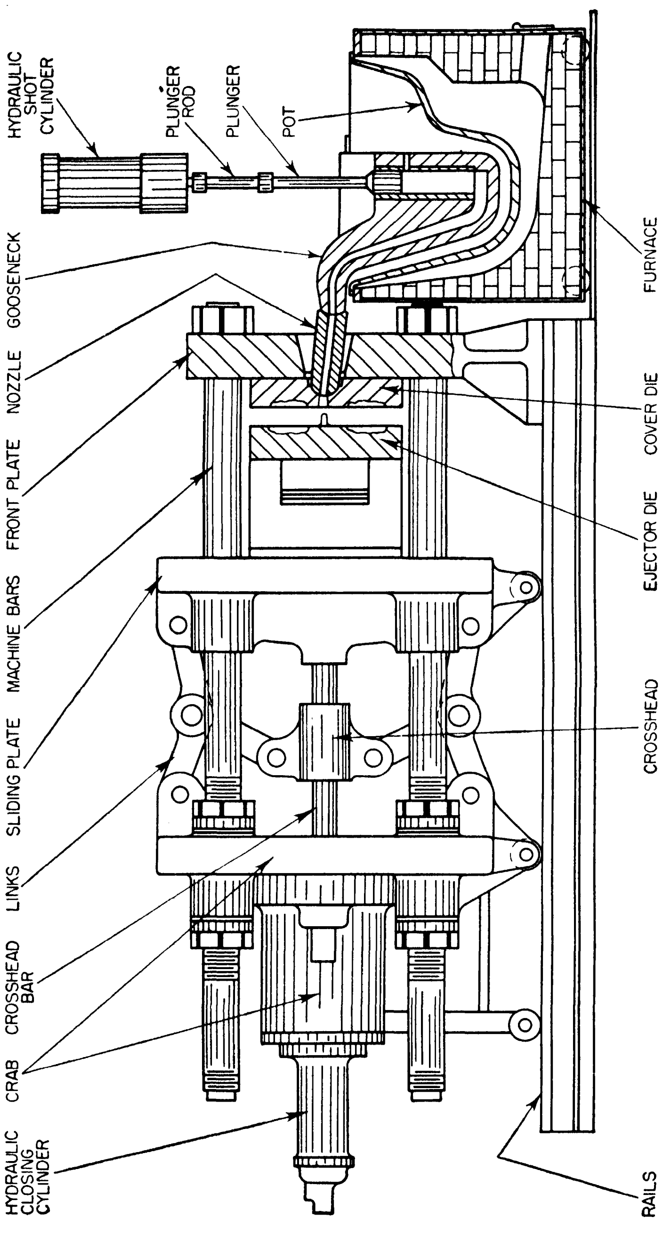


Fig. 1.3. Modern 48-in. submerged-plunger machine for the casting of zinc. Most modern machines are hydraulically operated and are equipped with automatic cycling controls and safety devices, as is this model.

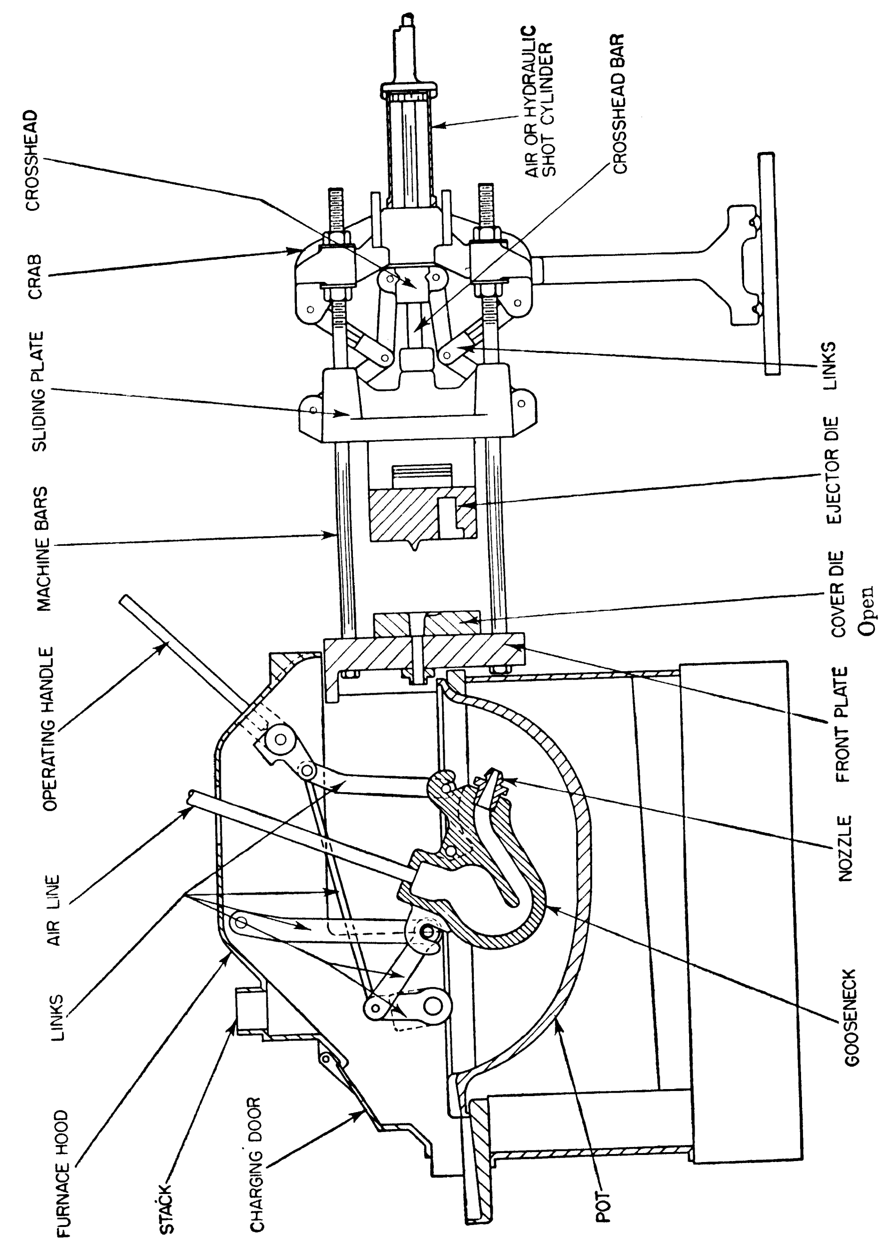
The present submerged-plunger die-casting machine (Fig. 1.3) does not differ in principle from the latter machines, except that hydraulic power has supplanted pneumatic power and manual labor has been greatly reduced by the introduction of timing devices, electric solenoids, electrically controlled valves, relays, and numerous limit switches, all of which make its operation practically automatic. The typical sequence of operation is as follows: Starting from the open position, the operator pushes a starting button which withdraws ejector pins from the die surface and moves the cores into place. The machine closes and locks, and immediately upon locking, the plunger moves forward to inject the molten metal into the die cavity. At the end of a predetermined time interval the plunger returns, the machine opens, the cores are withdrawn, and the ejector pins move outward to eject the casting. The operator cleans and lubricates the die surface and pushes the starting button to start another cycle.

Air Machines. Aluminum die castings cannot be produced in a submerged-plunger machine because molten aluminum rapidly attacks and dissolves iron or steel parts, and a plunger and cylinder submerged in aluminum would readily become inoperative as a result.

The development of the "gooseneck" air machine for aluminum took place about 1915. Diagrammatic views of this machine in the open and closed positions are shown in Fig. 1.4. The machine consists of a cast-iron pot that holds the molten aluminum alloy and in which is suspended a ladle or gooseneck. The gooseneck is connected to the machine by a system of links, so that it can be submerged below the surface of the melting pot and filled with metal. The linkage is so arranged that the gooseneck can then be raised and the spout brought into contact with the sprue or gate of the die, at which point it is mechanically locked into place.

Operation of the Gooseneck Machine. First, the gooseneck is lowered into the molten alloy. The compressed-air connection to the lid is opened to the atmosphere by means of a valve. This allows the metal to flow into the gooseneck through the spout. The gooseneck is then mechanically lifted from the melting pot, thus allowing the surplus metal to drain from the spout. It is tilted backward slightly to prevent drip, and continuation of the stroke brings the spout into contact with the die orifice, where it is locked in position.

The valve leading to the atmosphere is then closed, and the valve from the compressed-air supply is opened. An air pressure of about 500 psi is applied directly on the molten aluminum to force it into the die. The compressed air is then shut off and the valve to the atmosphere opened, after which the gooseneck is again allowed to drop back into the melt



CROSSHEAD
CRAB
SLIDING PLATE
MACHINE BARS
OPERATING HANDLE
AIR LINE
LINKS
FURNACE HOOD
STACK
CHARGING DOOR
AIR OR HYDRAULIC SHOT CYLINDER
CROSSHEAD BAR
LINKS
EJECTOR DIE
COVER DIE
Open
FRONT PLATE
NOZZLE
GOOSENECK
POT

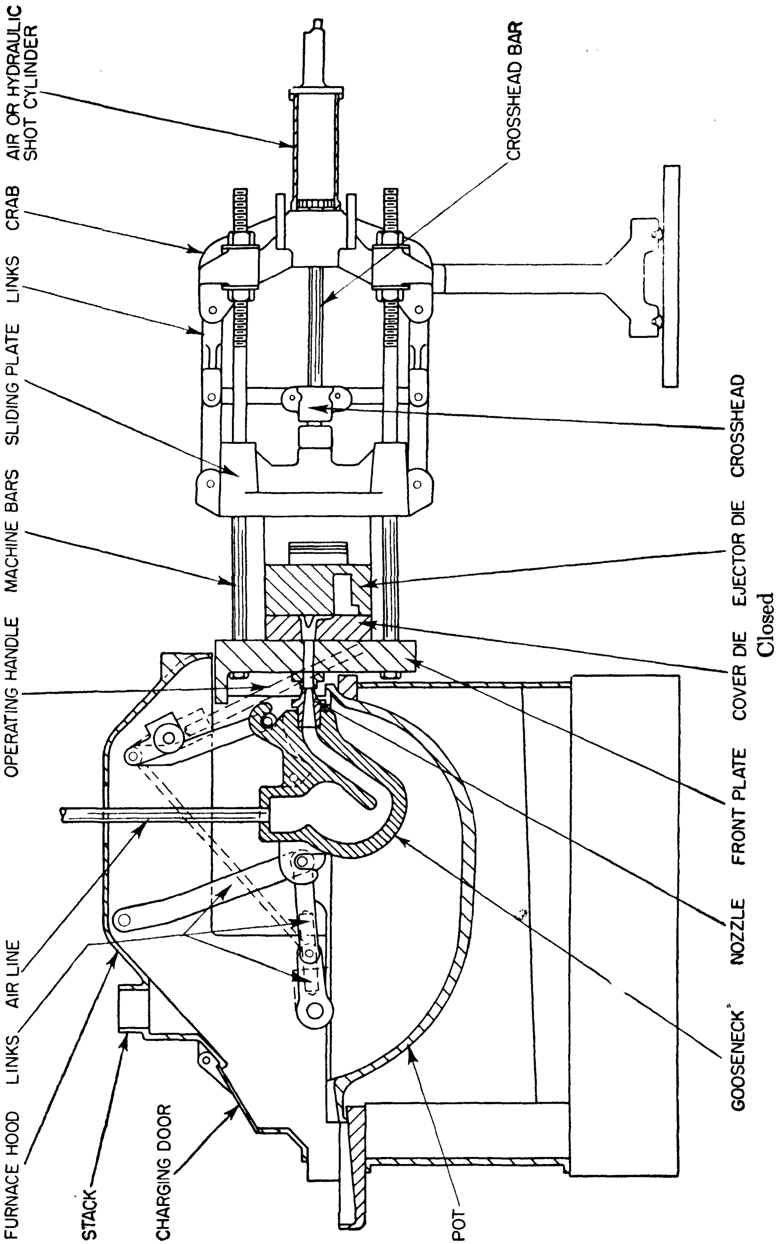
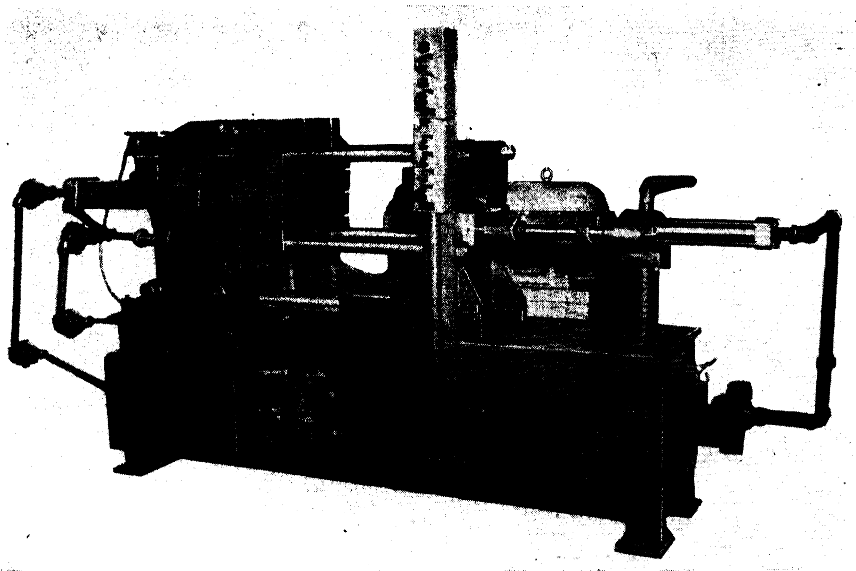
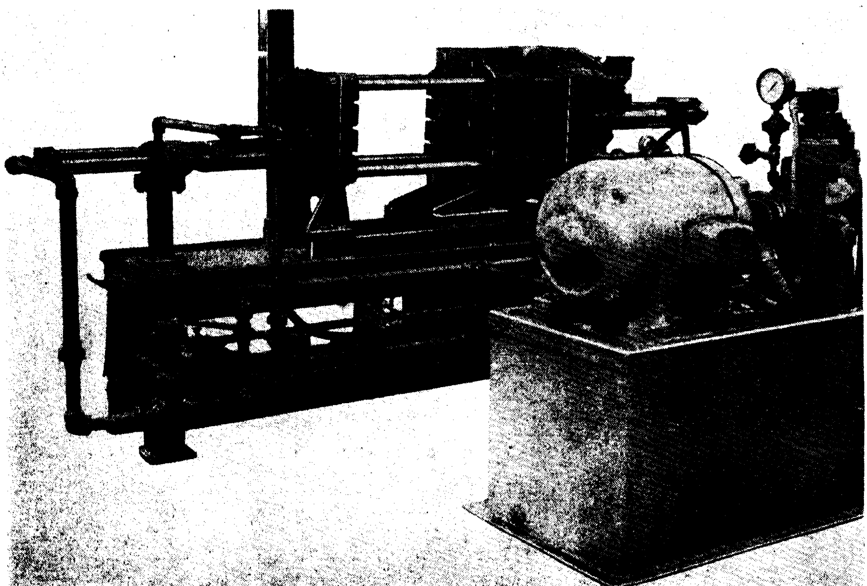


Fig. 1.4. An early 16½-in. gooseneck aluminum die-casting machine. Machines of this type were developed for aluminum because higher melting point alloys were contaminated by iron from the cast-iron pot of the submerged-plunger machine.



Front



Back

FIG. 1.5. Small, experimental self-contained casting machine of the cold-chamber type for casting aluminum alloys. The back view shows the hydraulic system.

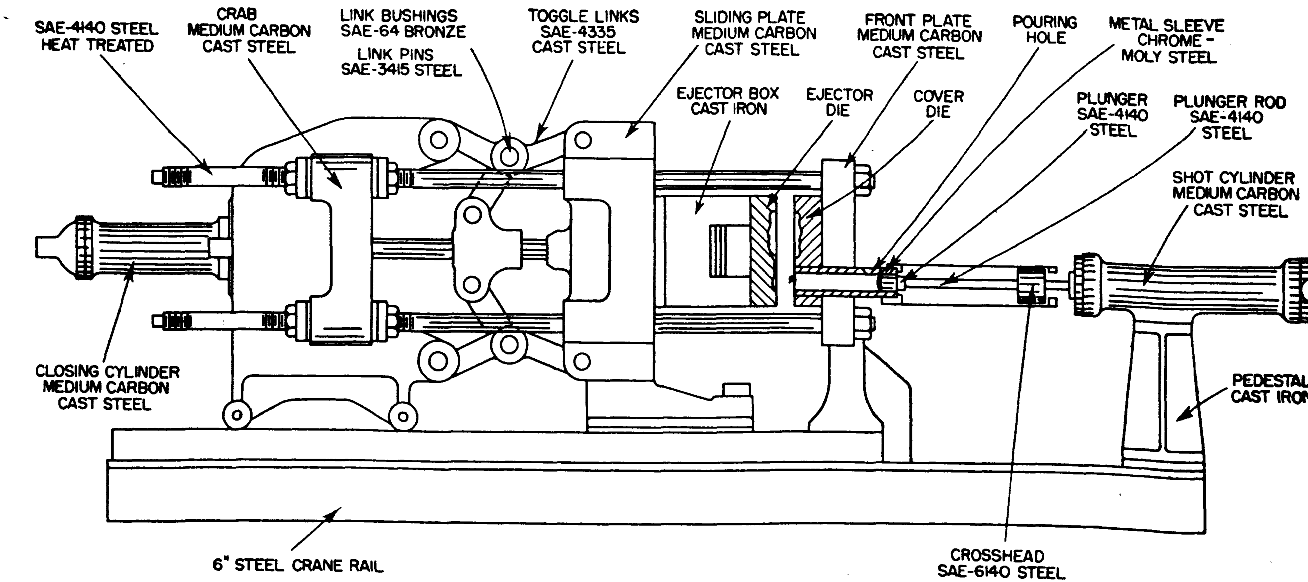
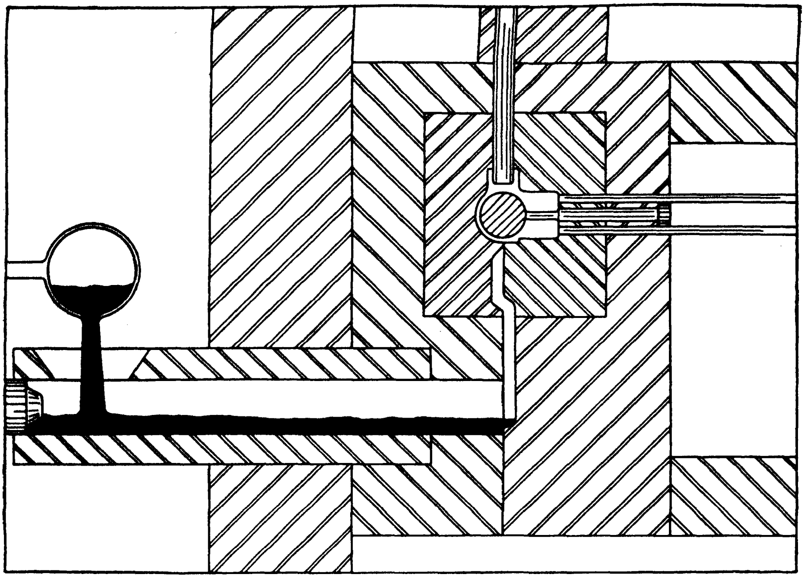


FIG. 1.6. Modern 21-in. cold-chamber machine, which has largely replaced the gooseneck machine in commercial production. Injection pressures as high as 30,000 psi can be developed with this unit.



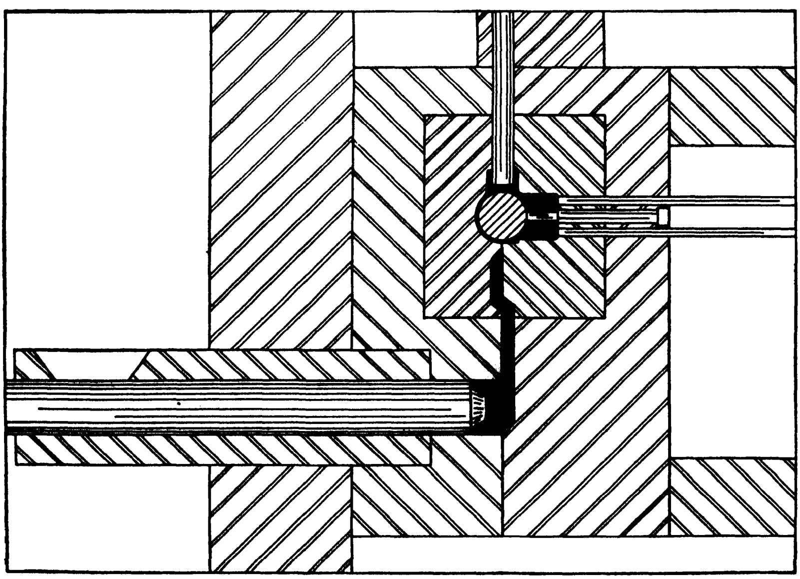
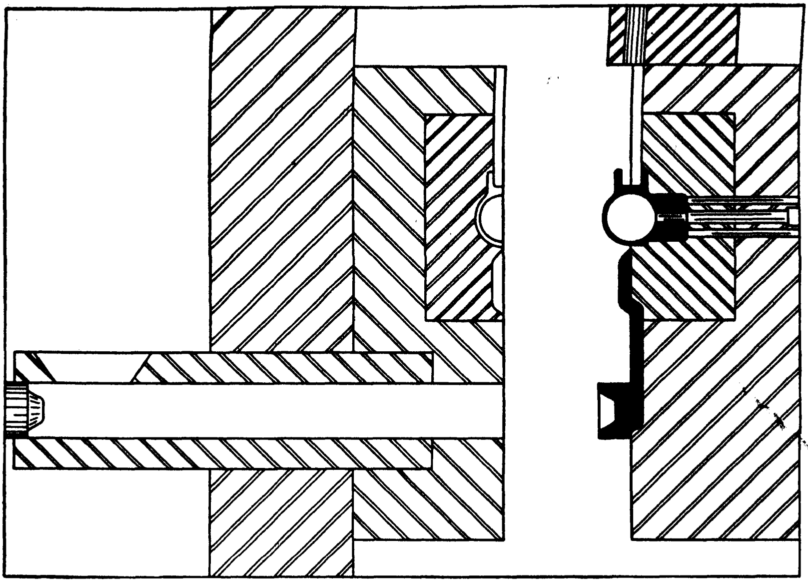
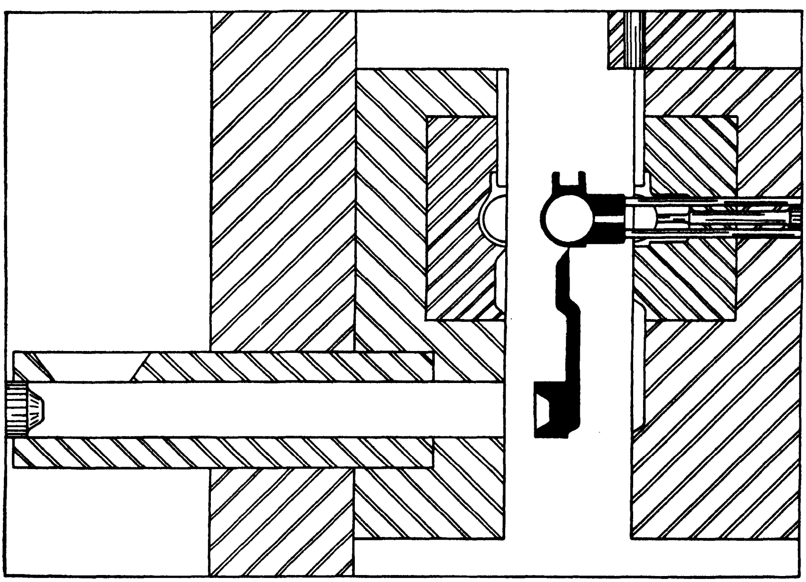


FIG. 1.7. Sequence in die-casting a part in a cold-chamber machine: *a*, the metal is ladled into the chamber; *b*, the plunger forces the metal into the die cavity;



c



d

c, the die opens; and *d,* the part, together with the gate and slug of excess metal, is ejected from the die.

to receive another charge. All the previously described operations are generally performed in synchronism with the other principal functions of the die-casting machine, namely, opening and closing the die, pulling the cores, and ejecting the finished die casting.

Although the gooseneck air machine is still being used to some extent for aluminum die castings, it is gradually being discarded in favor of the cold-chamber injection type (Fig. 1.5), chiefly because of the limitations on injection pressure and the adverse effect of iron, which is dissolved from the iron gooseneck and the holding pot, thus contaminating the aluminum alloy.

Cold-chamber Machines. The cold-chamber machine shown diagrammatically in Fig. 1.6 uses a hydraulically operated plunger to force molten metal into the die. The metal is first poured into the cold chamber by a ladle that holds enough metal for several die fillings. Immediately after the pouring operation, the plunger is advanced; it seals the port and forces the metal charge into the locked die under pressures as high as 30,000 psi. In all cases, enough metal is ladled to more than fill the die cavity; the excess metal, being in the form of a slug, is ejected with the casting. A sequence of the steps in casting a part with the cold-chamber machine is illustrated in Fig. 1.7.

Thus, in today's practice there are essentially two types of casting machine in most common use: the submerged-plunger injection machine, used for the casting of the lower melting point alloys of zinc, tin, and lead; and the high-pressure cold-chamber injection machines, used for the die casting of the higher melting point alloys of aluminum, magnesium, and brass. In both of these basic types of machine the back, or closing, ends are essentially identical. The only difference is in the injection system, and the machines may be made interchangeable by standardizing the back end so that either a submerged-plunger or a cold-chamber injection system can be used.

DETAILS OF THE MODERN MACHINES

The size of the modern machines, designated by the distance between the center lines of the bars that hold the movable and fixed halves of the die together, may run from a 12-in. size or smaller to one that is 48 in. or more. An intermediate-sized machine of approximately 21 in. is one which is in common use, since it accommodates a large number of dies.

Of course, the actual size and operational features of the machine depend upon who makes it. Various types of machines are manufactured in sizes to suit the requirement necessary for producing castings of given sizes and weights. Some of the smaller machines are built for

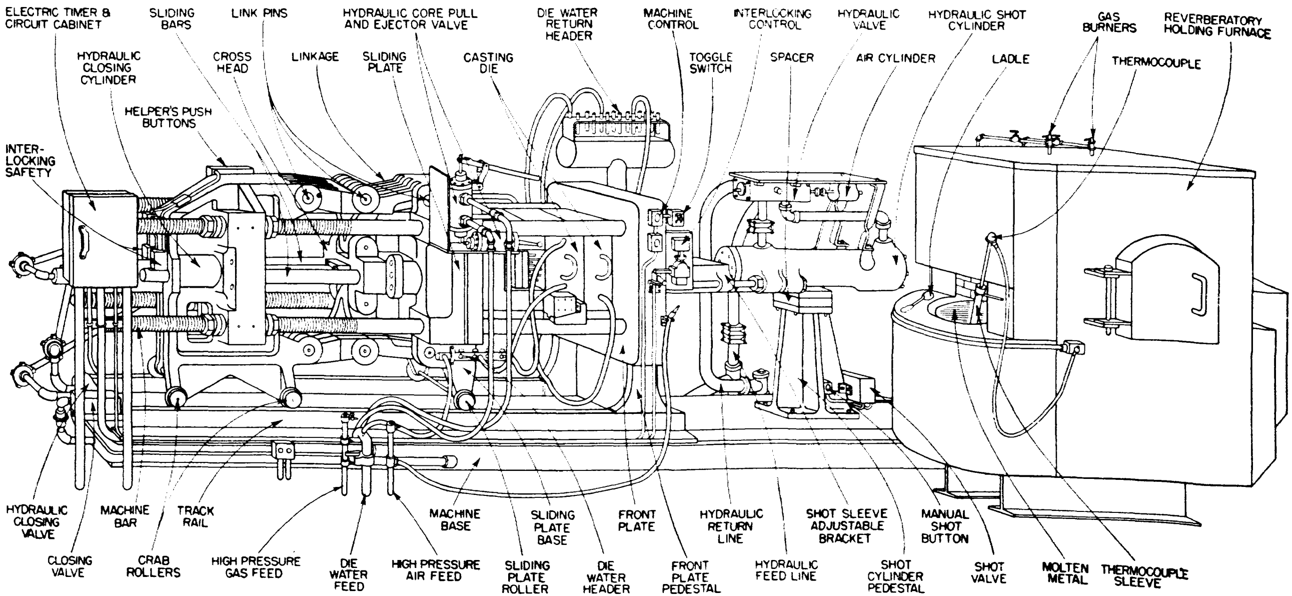


Fig. 1.8. Detailed isometric view showing all major components of a modern cold-chamber die-casting machine. Although each machine may differ somewhat, depending upon the manufacturer, they are all quite similar in principle.

complete automatic cycling so that the same part can be produced day after day without changing dies.

In most designs the trend seems to be toward the four-bar horizontal hydraulic machine (Fig. 1.8), which is built to operate either from a central hydraulic system or with an oil hydraulic pump and reservoir as part of the machine. In others, the bars are eliminated and the frame is cast as one member to support the various moving parts.

No such thing as a universal machine exists, since each manufacturer considers his machine the best in the industry. Because designs vary, dies that are built to fit one type of machine usually cannot be adapted to fit others without expensive alterations. Limitations in the die opening and maximum die heights in such machines have caused many of the larger die-casting companies to design their own machines. It is not uncommon for some of the larger producers to be called on to produce from dies with over-all heights of from 14 to 46 in. Thus it is apparent that the standard commercial machine may have rather limited use in some of the large jobbing shops.

Die-locking Methods. There are three types of die-closing and locking mechanisms: (1) hydraulic with toggles, (2) straight hydraulic, and (3) mechanical. For machines operating with high injection pressures, it is absolutely essential that the entire casting machine be of rugged construction so that when the injection pressure is applied the dies will not be forced apart.

Hydraulic Mechanisms with Toggles. The hydraulic-with-toggles type of die-closing and locking mechanism shown on the machine in Fig. 1.9 seems to be the preferred and accepted method in many casting machines. With some other designs where toggles are used they are actuated by air, electric motor, cams, or hand. With the toggleless machines or those operated by straight hydraulic pressure, die closing and locking is accomplished by fastening the sliding plate directly to the closing piston or ram.

The casting machine generally consists of a fixed front plate, a sliding plate, a crosshead, and an end frame, all connected together by either fixed or adjustable machine bars that act as tie rods. The sliding plate, crosshead, and end frame are connected together through the links and link pins and provide the motion for opening and closing the die. The closing pressure must be sufficient to stress the machine bars in order to keep the die closed while the metal is being injected into the die cavity. Should the die be open slightly while the cavity is being filled, molten metal will escape into the plane parting and the pressure within the die cavity will drop. Not only does this useless dissipation of pres-

sure cause the casting to be offsize and have excess flash, but also, if the dies are open far enough, the molten metal forced into the surrounding area endangers the operator.

Since every die varies and frequent die changes are necessary, especially in jobbing work, provision must be made for adjustments in the locked position of the machine to accommodate dies of different heights. Some machines are adjusted by means of nuts on each of the machine bars; on others, the adjustment of the nuts is synchronized. On the

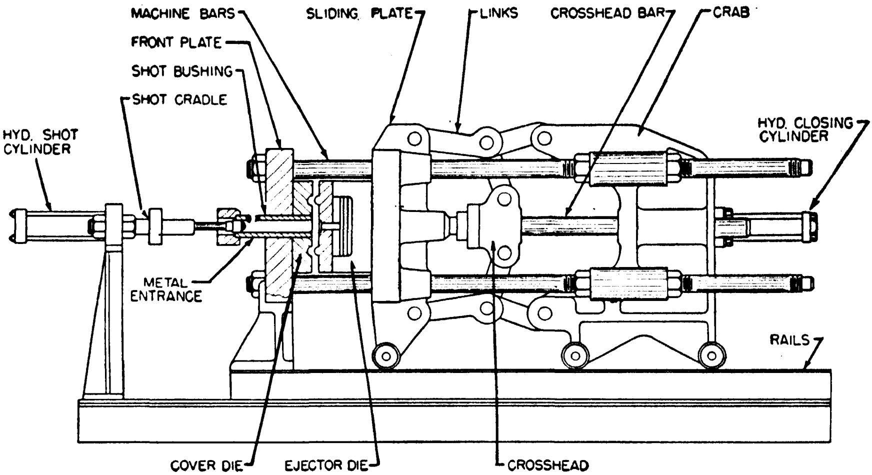


FIG. 1.9. Small (21-in.) submerged-plunger machine having a hydraulically operated toggle mechanism that closes the machine and locks the die in place.

smaller machines, adjustment is sometimes made through a single centered screw to eliminate the misalignment that may occur in adjusting the nuts on the machine bars. In any case the adjustment of the machine is very important. Too much overlap in locking the die will cause the die to slam together and overstress the links and pins, thus causing breakage and die damage. Insufficient locking will allow the shot to escape and may cause the dies to warp. Lubrication of moving parts is very important to prevent sticking, wrenching of the pins, or galling of mating members.

Straight-hydraulic Mechanisms. In machines using straight-hydraulic pressure for closing and holding the dies, the sliding plate is usually moved toward closing at high speed and under lower pressure for a predetermined distance, after which higher pressure is applied at slow speed to the piston or ram to hold the dies closed while the cavity is being filled. The die is opened at high speed, the piston or ram slowing down toward the end of the stroke. The speed and pressure build-up on the

piston or ram is adjustable through adjustments of the pump, relief valve, or other valves.

On some machines, hydraulic pressure is obtained by using two oil hydraulic pumps, one operating at low pressure and the other at high pressure. On others, differential pistons are used for closing the die, with the final locking pressure coming from an intensifier. High closing pressures can be obtained from several different booster oil systems that build up and hold the die-closing pressure with a minimum of pumping. All such hydraulic systems, however, are rather complex and may require many adjustments in order for the various valves to function in sequence.

Mechanical Locking Mechanisms. In machines using a mechanical mechanism for closing and locking the dies, motion is usually obtained from either cams or linkages that are connected directly to the toggles or to the sliding plate. Power is obtained from an electric motor. Many small casting machines are in use with mechanical-electric, mechanical with cams, mechanical plus air cylinders, or cam plus manual operation methods of closing.

Injection Systems. For all low-melting-point alloys which do not attack the machine parts, the submerged-plunger injection system is used. With this method a metal cylinder and plunger are submerged in a pot of molten metal with the injection plunger connected to an air or hydraulic shot cylinder which is above or to one side of the furnace, as previously described.

The metal cylinder is held within a cast-iron pot that sits in a well-insulated, round or rectangular oil- or gas-fired furnace (Fig. 1.10). A passage leads from the bore in the cylinder and through a nozzle into the sprue opening in the die. With the plunger retracted, molten metal from the pot is admitted through ports in the metal cylinder, thus filling the cylinder up to the bottom of the plunger and the passage up to the metal level in the pot. On the downstroke, the plunger first seals off the ports and then pushes metal through the passage into the die. Because the cylinder stroke and pressure are constant, the metal cylinders and plungers must be selected in sizes large enough to fill the cavity and runners in the die. Metal cylinders are made of iron, steel, or Meehanite castings, or alloy forgings. In cast cylinders, the latest practice in the industry is to shrink a heat-treated and nitrided sleeve within the cylinder bore to minimize wear due to the stroke of the plunger. Cylinders made from alloy bar stock or forgings are used without sleeves, being heat-treated and nitrided before use. Plungers are made from cast iron, Meehanite, or alloy steels. Some are used with cast-iron piston rings to retain pressure on the metal, some are used without rings, and others —those of alloy steel—are hardened to reduce wear.

For high-melting-point alloys, the cold-chamber injection system is preferred in order to minimize iron pickup or other alloy contamination. There are two types of cold-chamber shot ends: *horizontal* and *vertical.* With both, the metal cylinder, plunger, and furnace that are used on the submerged-plunger machine are removed from the back end of the front plate.

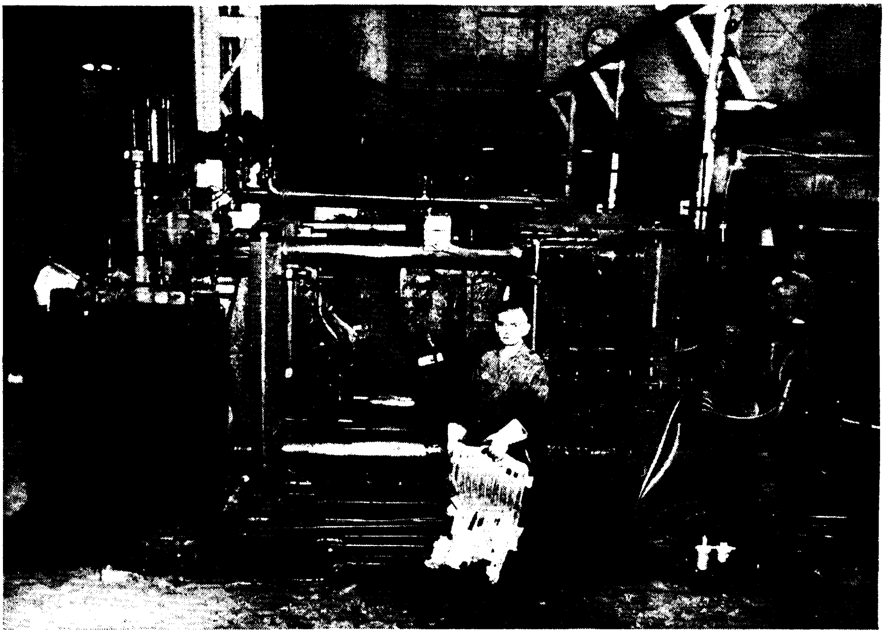


FIG. 1.10. One of the larger types of submerged-plunger machines tooled for the production of zinc automotive grilles. The holding furnace is at the front of the machine.

In machines using the horizontal shot end, provision is usually made in the front plate for locating the metal sleeve in two positions, one in the center line of the plate and the other below center. The gate location in the die determines which metal sleeve location is used so that the die will balance in between the machine bars. The round metal sleeve, which is the "chamber" leading to the gate in the die, has an opening cut in its outer diameter to permit molten metal to be poured into the inside. This sleeve in almost all commercial die-casting machines is held in a fixed position in the front plate. A sleeve with a projecting shoulder and of corresponding bore size is placed in the cover half in the front plate, thus aligning the bores in both sleeves. Sleeves are made of various heat-treated steels so that they will withstand the thermal shock

encountered with different alloys. Because the stroke of the shot cylinder is fixed, it is important that metal sleeves be chosen with bore sizes enough to contain a sufficient volume of molten metal to fill the cavity in the die.

The plunger tip is fastened at one end of the plunger rod, which is coupled through a crosshead to the piston rod of the shot cylinder. To prevent excessive expansion of the plunger tip while in contact with the molten metal during the time the shot is being made (which may result in the tip sticking in the metal sleeve), the inside is hollowed out to permit the entrance of cooling water from drilled holes in the plunger rod.

The hydraulic shot cylinder is fastened through two or more heavy tie rods or a bracket to the back of the front plate. These shot cylinders are sometimes changed to correspond to a change in metal sleeve size in order to maintain the necessary injection pressure on the metal. On some machines the shot cylinder is supported rigidly from a base so that weave due to surge of the oil filling the cylinder is held to a minimum.

Another type of round metal sleeve sometimes used is in one piece and runs through the front plate to the parting line of the die. This type of sleeve is adjustable to suit the cover-die thickness. It is the preferred type, since it eliminates the possibility of one of the fixed sleeves being out of size due to rehoning of the bore, which may be done to obtain a smooth inner surface.

Shot cylinders with booster pistons are sometimes used to replace the standard cylinder. In these booster cylinders the large actuating piston moves over a fixed smaller piston that has a hollow drilled piston rod. Oil is admitted through the hollow piston rod against the smaller piston, which moves the booster piston for a predetermined distance; then the hydraulic pressure is shifted to the larger piston to sustain a higher injection pressure on the metal as it chills in the die.

Another type of booster shot cylinder is operated by a prefill system. Oil is admitted through the hollow piston rod against the smaller piston at 1,000 psi; this carries the larger booster piston forward. As the large piston moves forward, oil flows by gravity from a tank through a prefilled check valve to fill the space behind the large piston. When the die cavity has been filled, the prefill valve to the tank is closed and oil at 2,000 psi from the booster pump is applied directly against the large and small pistons, thus holding the higher injection pressure on the metal.

Machines with the vertical-type shot ends for cold-chamber injection systems are a European importation, although some now are being manufactured in this country. The closing frame is the straight-hydraulic horizontal type with three, four, or six fixed tie rods. The vertical shot

cylinder is mounted directly over a thick front plate that is recessed to hold the cold chamber and cut out at the top to provide space for pouring in the molten metal (Fig. 1.11).

The metal sleeve or chamber is bored into a rectangular block of steel that rests against the back of the die when the die is fastened to the front plate. A sprue bushing in the side of the block connects with the

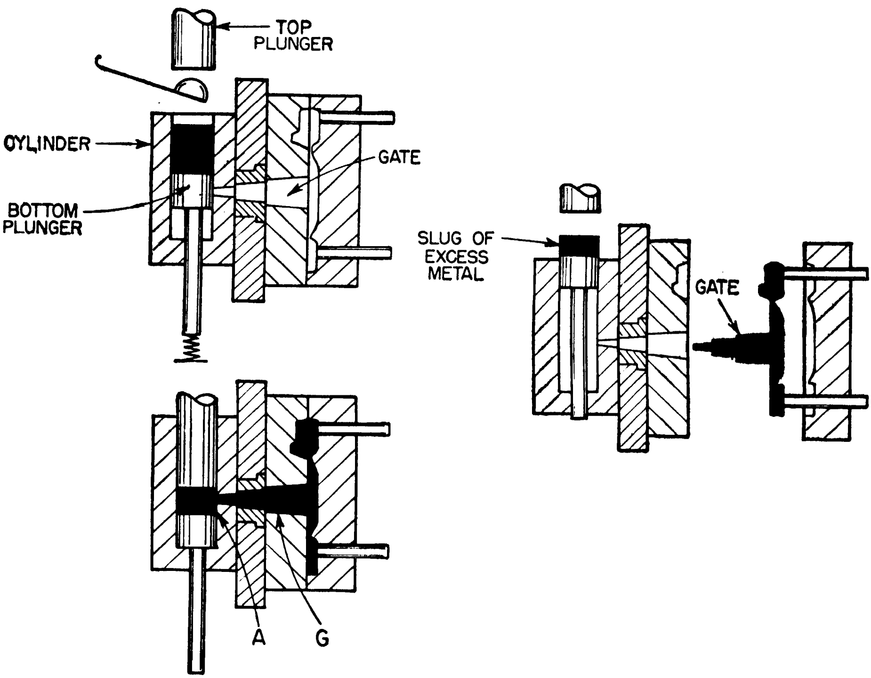


FIG. 1.11. The Polak machine, a European innovation, is a cold-chamber type having a vertical shot end. One objection to this type is that the plunger is not water-cooled and sometimes sticks during the injection stroke.

sprue hole in the die to provide an entrance for the metal. At the bottom of the metal sleeve is a plunger, spring-loaded in such a way that it closes off the hole in the sprue bushing to prevent molten metal from running into the die cavity. The top plunger is above the opening in the metal shot sleeve and is fastened to the piston rod of the shot cylinder.

The molten metal is poured in the sleeve and over the bottom plunger. When the shot is started, the top plunger enters the metal sleeve, pushes down the bottom plunger, and injects the molten metal into the die cavity. After the injection cycle has been completed, the excess metal, which has formed slug *A* (Fig. 1.11), is automatically sheared off sprue *G* by the bottom plunger and is pushed up above the sleeve, where it is

ejected. The bottom plunger then returns to its normal position ready for the next filling.

One serious objection to the use of the vertical shot system is that the plungers are not water-cooled, as in machines using the horizontal shot system. As a result, the plungers expand and sometimes stick in the metal sleeve during the working stroke, necessitating down time and perhaps removal of the die in order to free the plungers.

Automatic Cycle Control. To obtain casting uniformity and maximum speed of operation, a definite predetermined interlocking cycle control must be used. Pressures and temperatures must be regulated automatically, and the dies must remain closed for a predetermined length of time while the cavity is being filled with molten metal and then opened in accordance with the selected time pattern or schedule.

Opening and closing the dies according to a time pattern is very important for a metallurgical reason. The molten metal that is injected into the cavity must be permitted to solidify completely before the dies are opened. If the dies are opened before the metal in the die has solidified, the casting may be distorted when it is ejected from the cavity; or if the casting is allowed to remain in the die cavity after it has solidified, shrinkage occurs that may severely stress the internal structure of the casting. If the metal comprising the plug of castings made on cold-chamber machines has not solidified completely when the die is opened and the plunger moves forward to eject the casting, there is the possibility that the plug may explode and injure the operator. Removal of the casting immediately after solidification is therefore essential.

A regular time cycle of operation also maintains an even die temperature, which is necessary to obtain a good finish on the casting. It also makes removal of metal from the furnaces uniform and helps materially in scheduling refilling when the molten metal is delivered from a central foundry. Thus, automatic cycling is recognized as being essential for continuous production of castings. Modern casting machines are equipped with electric timers and other electrical devices that control the various valves in sequence, in accordance with a set pattern.

Some cold-chamber machines have semiautomatic controls. The shot is made at the operator's discretion. After each pouring of molten metal he operates a foot or hand air valve to actuate the shot cylinder. Such machines, however, have automatic controls for opening and closing the die so that it is not left to the operator to guess "from shot to shot" how long he thinks the die should remain closed and when it should be opened.

Several types of automatic ladling devices have been developed that automatically pour molten metal into the metal sleeve when the dies are fully closed. These are exclusively for use with cold-chamber machines, and their operation is tied in with the automatic cycling of the machine.

With all automatic or semiautomatic machines the timing controls can be adjusted to obtain the desired closing and opening intervals to suit the conditions in the dies. All operations of the machine can be controlled manually by the operator, this being very essential when die changes have been made, to make sure that all moving parts in the die function properly. Hydraulically operated core-pull and ejector mechanisms can also be tied in with the opening and closing cycle when desired, thus relieving the operator from manually operating such mechanisms.

Other automatic controls for regulating the amount of circulating water necessary to keep the die temperature uniform during the casting operations are sometimes used for critical jobs. On the other hand, certain dies require heating elements located within the die to control finishes. Such controls are used whenever necessary.

Oil vs. Water Hydraulic Systems. The hazards involved in using oil for commercial casting machines are known to the industry; but because oil-operated pumps and valves in various sizes and ratings are readily available, the machine manufacturer meets competition and price by their use.

With oil-operated casting machines, there is always the possibility of fire. With a furnace in which molten metal is located near high-pressure oil, every possible precaution must be taken. Pipe fittings are usually brazed or welded to prevent leakage, and trombones or swivel joints are used between moving parts. However, when hydraulically operated core pulls and ejection systems are used, the hydraulic cylinders and valves must be removed when die changes are necessary.

As shown in Fig. 1.12, there may be quite a number of such connections, and consequently there is apt to be leakage around the casting machine. To alleviate this fire hazard somewhat, synthetic high-flash-point oils and certain types of organic materials such as some of the aromatic chlorinated hydrocarbons and tricresyl phosphate (Lindol), with boiling points in the neighborhood of 600°F, have been used to some extent.

While self-contained commercial casting machines are being used by many producers, some of the larger die-casting companies have been operating their machines from central systems. Eliminating the pumps

and motors from each casting machine permits a larger pump to be installed at a remote place from the casting department, and pressure is supplied through large pipes to a group of machines.

Other large producers, recognizing the hazards of operating with oil, have installed central systems using water as a medium. Machines operating from such a system require less floor space and accessory

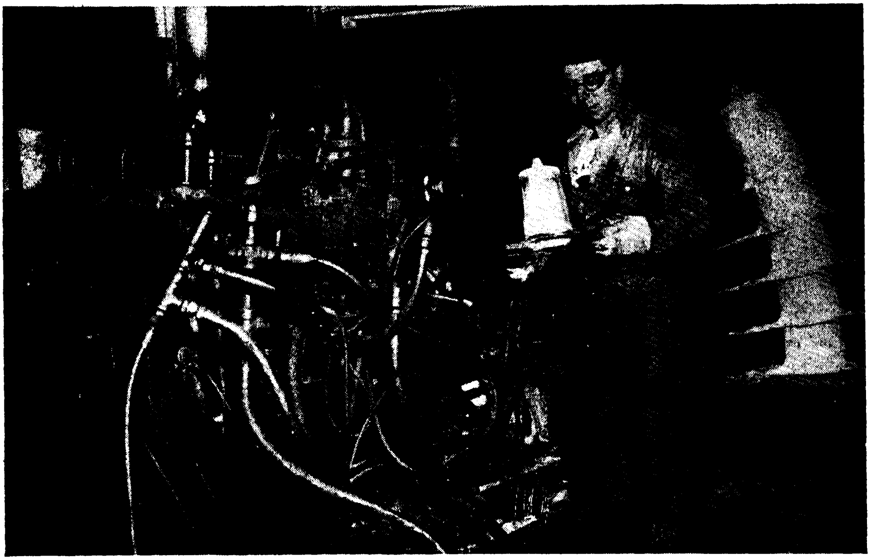


FIG. 1.12. If oil is used as the actuating medium for the casting machine, core pulls, and ejector mechanism, leakage through the connections or when dismounting the die may create a fire hazard.

equipment. With water under high pressure, all hydraulic equipment must be fitted with much closer tolerances than are necessary when the same equipment is operated with oil, but leakage is not a hazard any more since water on the floors can run down the drains, and repairs can be much more easily made.

Central-system operation requires a pattern of safety devices that is not used on the self-contained oil-operated machines. Protection for the operator should be paramount. There is always the possibility that the closing-cylinder piston rod may break, causing the machines to reclose and injure the operator. With the self-contained machine, it is only necessary to push the button to stop the pump motor so that there will not be any pressure to the cylinders; with machines operated from a central system, pressure shutoff is dependent upon a globe valve between the pressure main and the casting machine.

Interlocks and Safety Devices. A careful study should be made by the producers of die castings as to the cause of accidents that either injure the operator or damage the equipment. A serious accident that injures an operator not only upsets the morale of a casting department, with a resultant loss of production, but also increases insurance rates and compensation claims and may involve a company in a lawsuit. Therefore consideration should be given to every moving function of the die or casting machine from the safety angle. The compensation costs for the loss of a hand that is caught in a die will more than pay for additional safety equipment to prevent another such accident. Another advantage of safety equipment is that it prevents damage to the die-casting machine, to the die, and to the cast part. For example, with hydraulically operated cores on dies it is not uncommon for the operator to operate the core-pull valve to return the cores while the ejector pins are in the ejection position, thus shearing off some of the pins and damaging the core itself. An interlock can be placed on the valve, with limit switches on the cores and ejector plates, so that the sequence of moving parts in the die can be controlled. The hydraulic core-pull or ejection valve can be remotely operated from a push button conveniently placed for the operator, or automatically operated by the movement of the machine when the dies open. The protective devices consist of the following:

1. Solenoid-controlled interlocks to lock the machine in open position. Should the piston rod in the closing cylinder break when the machine is opening, pressure is applied directly to the end of the piston rod, which causes the machine to start reclosing. These interlocks drop into any of the staggered notches in the crosshead bars and prevent the die from closing.
2. A solenoid-controlled interlock to lock the four-way hydraulic closing valve when the machine is in the closed position during the time the shot is being made. Should this valve be operated during the shot period on the submerged-plunger machines, the dies start opening and the plunger in the metal cylinder keeps on forcing molten metal between the die halves until the end of the shot stroke.
3. A solenoid-controlled interlock to lock the four-way hydraulic shot valve when the machine is in the open position.
4. A push button to enable the operator at any time to reset all operating controls to open the machine.
5. An electric-eye control to protect the operator from approaching the die while the machine is closing.
6. Push buttons so arranged that when a helper is required, he must use both hands to keep them in contact before the operator can start to close the machine.

Other electrical accessories such as timers, relays, and limit switches are used to complete the circuit, which functions automatically for a complete cycle.

OPERATION OF DIE-CASTING MACHINES

How Submerged-plunger Machines Operate. Although many manufactured casting machines operate in a somewhat similar manner to accomplish the result of producing die castings, they differ to some extent in constructional and control details.

Controls for one type of submerged-plunger hydraulically operated machine (as made by the Doehler-Jarvis Corporation for use in its own plants) are shown in Fig. 1.13. The machine is started by the operator pushing a button to begin the cycle; the machine is then operated automatically through electrically actuated controls until it opens and resets for the next cycle. The use of the electric-eye control for safety has made possible the placing of all controls within easy reach of the operator so that he has no occasion to walk back and forth, either to start the closing cycle or to dispose of a finished casting. It enables the operator to start the cycle safely with one hand through one push button while he holds tongs in the other since, if the beam is interrupted, it will not permit the machine to close.

The light beam from the control is reflected back and forth across the full die height by mirrors. Should the light beam be broken at any point when the machine starts to close, the control is so wired that it will immediately reverse the travel and the die will open. If the reflecting mirrors are dirty or if they have been disturbed so that the light beam does not carry to the eye, the machine cannot be closed because the photoelectric controls will cause it to remain open until the trouble is found and corrected.

The eye is effective over all but the last 2½ in. of travel of the crosshead, at which point the die is actually closed and it is impossible for any part of the human body to be interposed between the die halves. After the crosshead has traveled the full distance, the machine is held in the closed position by the electrical controls until after the shot is made. This prevents the machine from reopening after the shot has started. When the machine has completed a cycle and the die is opened, the operator, by removing the casting, breaks the beam, which resets the controls for the next cycle. If the beam is not broken at that time the machine cannot be closed again. This is an added safety feature, for if a light from another source which is not broken by the normal oper-

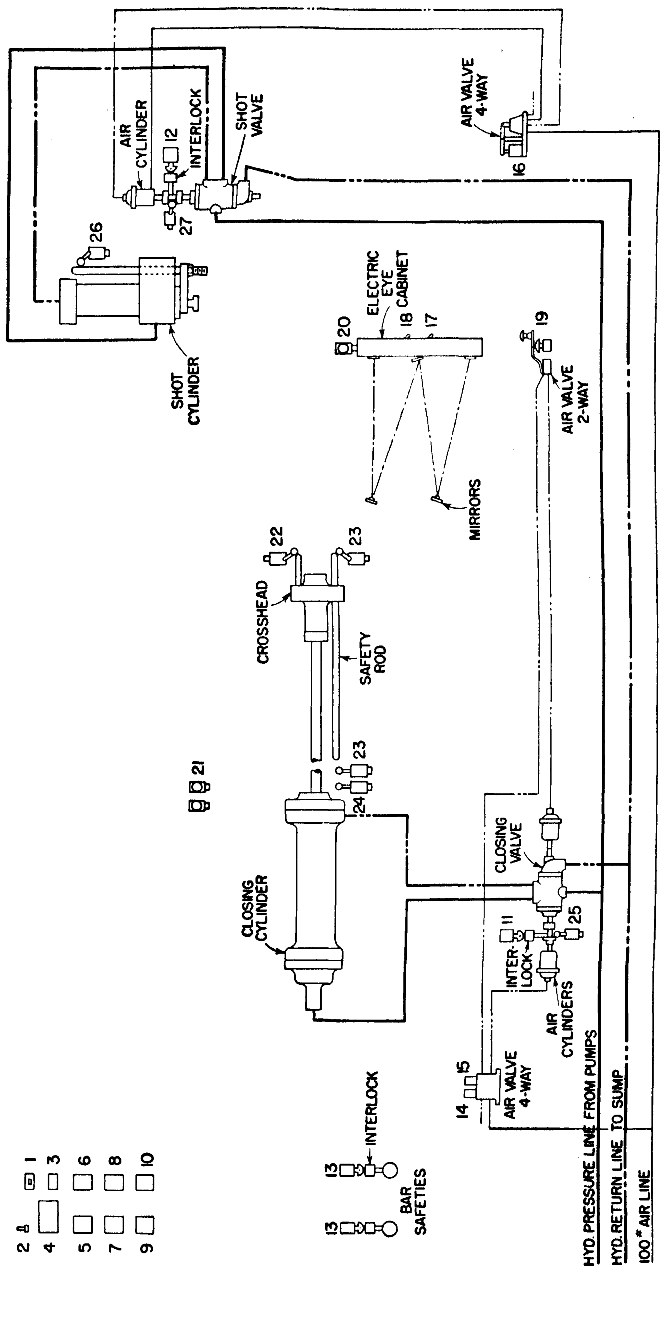


FIG. 1.13. Schematic diagram of electric and hydraulic controls and interlocks for submerged-plunger machine. See text for details of operation.

ation of the machine causes the eye to remain actuated, or if the contacts of the photocell cocking relay should stick, the machine cannot be closed. The working principle in starting a cycle is as follows:

The operator turns on circuit breaker No. 1 and main switch No. 17, which feeds all circuits except that causing the shot. The light in the electric-eye cabinet goes on, and relay No. 8 is actuated and held in contact until the crosshead reaches a point 2½ in. from the closed position, where limit switch No. 24 is made. After about a 15-sec delay for the thyratron tube in the electric-eye control to heat up, current passes from photocell cocking relay No. 8 to one side of reverse relay No. 5, the closing actuating relay No. 7, and the closing push button No. 19.

Shot-control switch No. 18 is then turned on, and pilot light No. 2 goes on to indicate that the machine is ready to go through a complete cycle. As the operator pushes on the latch fastened to the two-way air valve and over push button No. 19, the circuits are made to operate closing actuating relay No. 7 and reverse relay No. 5, which opens the machine if the light is interrupted. At the same time, the solenoids of bar safeties No. 13 and the closing-valve interlock No. 11 are energized to take out the interlocks, while that of four-way air valve No. 15 opens the porting in the valve so that air flows to the two-way air valve.

The two-way air valve (normally open to exhaust) which has been closed by the operator permits air to flow into the one-way air cylinder to slide the hydraulic valve over so that hydraulic pressure can enter into the closing cylinder to close the machine. As the crosshead moves to the closed position, limit switches No. 23 actuate closing safety relay No. 10, while limit switch No. 27 deenergizes solenoid No. 11 to drop the interlock in order to keep the closing valve locked during the shot period.

If the light beam has not been broken as the machine closes, the safety rod that is fastened to the crosshead moves away from limit switch No. 24, which makes and then deenergizes opening actuating relay No. 6 and energizes closing actuating relay No. 7 so that the machine will remain closed until the contacts are broken automatically by electronic timer No. 4 or manually through push button No. 20.

The safety rods on the crosshead will also make limit switches Nos. 22 and 23. Limit switches No. 23, which are in series, actuate the cycle-control relay No. 9, which feeds electronic timer No. 4. Limit switch No. 22 energizes solenoid No. 12 to take out the interlock on the shot valve and also energizes solenoid No. 16 on the spring-return four-way air valve. This valve opens to permit air to flow into the two-way air

cylinder to slide the hydraulic valve over so that hydraulic pressure is put on the shot cylinder to make the shot.

As the shot starts, the safety rod fastened to the shot-cylinder piston rod moves away from limit switch No. 26, breaking the circuit. After electronic timer No. 4 has been on for the predetermined interval, the normally closed contacts of cycle-control relay No. 9 break, solenoid No. 16 of the air valve is deenergized, and the spring opens the other port, thus permitting air to flow into the other side of the air cylinder to reverse the hydraulic shot valve and the shot cylinder. As the shot piston in the cylinder returns, the safety rod remakes limit switch No. 26, causing the normally open contacts of electronic timer No. 4 to actuate opening actuating relay No. 6, which reenergizes solenoid No. 11 to remove the interlock that keeps the closing valve locked during the shot. Solenoid No. 14 of the four-way air valve reënergizes, letting air flow into the other one-way air cylinder to reverse the hydraulic closing valve so that the machine starts opening. As the machine continues to open, limit switches Nos. 22 and 23 return to their normally open position and all relays reset for the next cycle.

How the Cold-chamber Machine Operates. The protective devices on the machine frame of a cold shot machine are somewhat similar to those used on the submerged-plunger machine, as shown in Fig. 1.14. The working principle in starting a cycle is as follows:

The operator turns on circuit breaker No. 18, which feeds all circuits, energizes solenoid No. 10 on the four-way valve to permit air to flow into the single-way air cylinder to keep the hydraulic valve in the open position, and energizes the normally closed contacts of push button No. 16 and limit switch No. 19.

To start the closing cycle, the operator must use both hands, one to push closing button No. 16 and the other to close the two-way air valve, which normally is open to exhaust. Push button No. 16 energizes solenoids Nos. 8 and 9 to remove the interlock; solenoid No. 10 is deenergized, closing the air-valve port; and solenoid No. 11 is energized so that the opposite port in the valve opens to allow air to flow through the two-way air valve into the one-way air cylinder. This cylinder slides the hydraulic valve over so that hydraulic pressure can enter the closing cylinder to close the machine. As the crosshead moves to the closed position, the safety rod causes limit switch No. 19 to break, shunting out push button No. 14.

The operator then ladles molten metal from the furnace and pours it into the metal sleeve, after which he pushes shot button No. 17. Through the action of the relay, solenoid No. 13 of the spring-return four-way air valve is energized, permitting the valve to open; air then flows into one

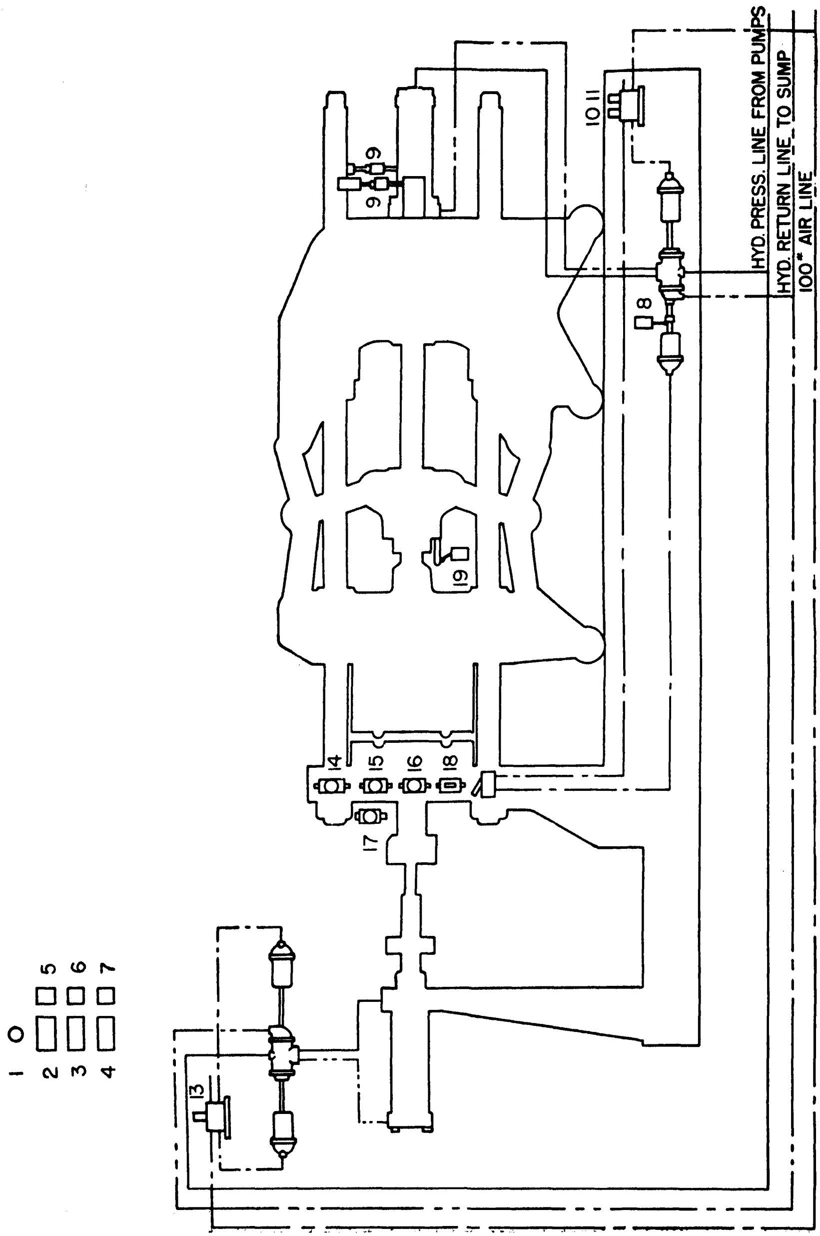


FIG. 1.14. Schematic diagram of electric and hydraulic controls and interlocks for cold-chamber machine. See text for details of operation.

of the one-way air cylinders to slide the hydraulic valve over so that hydraulic pressure is put on the shot cylinder to make the shot.

As the shot starts, electronic timers Nos. 2 and 3 energize and hold for the predetermined interval. At the time set for opening, electronic timer No. 2 deenergizes solenoid No. 11 and energizes solenoid No. 10 of the four-way air valve so that air flows to the other one-way cylinder. This action reverses the hydraulic closing valve so that the machine starts opening. The shot plunger, still under pressure, follows the opening of the die to push out the slug remaining in the metal sleeve. After electronic shot timer No. 3 breaks the circuit in accordance with the set interval, solenoid No. 13 of the spring-return four-way air valve is deenergized. This allows air to flow into the other one-way air cylinder to reverse the hydraulic shot valve and the shot cylinder. As the machine continues to open, all interlocks enter into locking position and relays reset for the next cycle.

If during the closing cycle the operator should release closing push button No. 16, the machine immediately reverses and opens. If the button is held until the machine is fully closed through limit switch No. 19, the machine will remain closed during the cycle. Push button No. 15 is so wired that the operator can open the machine manually at any time.

Occasionally it becomes necessary to try out the shot with the machine open. To protect the operator and to make sure that both hands are occupied, he must push both buttons Nos. 14 and 17 to start the shot. At other times, the type of die and castings require a definite pattern of closing to maintain uniform operating conditions. To ensure such relativity, electronic timer No. 4 is added to the circuit to delay the closing of the machine in accordance with the set pattern.

CHAPTER 2

DIE-CASTING DIES

As was pointed out in the introductory section, a die-casting die must be split into two sections so that the casting can be removed after it has been formed. These two sections are called the *cover die* and the *ejector die*. The cover die is fastened to the stationary platen on the casting machine and does not move during the casting cycle. The ejector half is mounted on the movable platen of the machine.

A cavity that is a reproduction of a section of the part that is to be cast is formed or machined in each of these dies. It is conceivable that half of the casting could be formed in the cover die and half in the ejector die, but this is seldom the case because the parting plane, *i.e.*, the mating surface of the die, is usually the plane having the greatest cross-sectional area on the part, and parts to be die-cast are seldom symmetrical. Although it is desirable to have the parting line in one plane, design consideration sometimes requires that it be irregular, curved, or slanted.

Both surfaces forming this parting line must be smooth and finished so that the die halves fit closely together. Otherwise a gap would exist through which molten metal could escape when forced into the cavity under pressure. It is also apparent that the two halves of the die must be in exact register when the die is closed, and the usual method of accomplishing this is to use dowel pins, as is done in stamping or drawing dies. These dowel pins are always placed in the stationary or cover-die member.

Other die components are shown in Fig. 2.1. These include the die base, an ejection plate and ejector pins, and surface pins. The die base is a cast-iron or cast-steel base on which the ejector die is mounted and in which is provided means of ejecting the casting. In the simple type of die, ejector pins are used to push the part from the ejector cavity after the casting machine opens. These pins are mounted in a plate called the *ejector plate,* and slide through holes in the ejector-die half. When the machine opens, this plate is pushed forward by some means, usually by a rack and pinion that may be hand-actuated or tied in with the machine cycle so that it is forced forward automatically at a predetermined point. Since the ejector pins must be flush with the parting surface of the

ejector die when the casting machine closes, surface pins and stop pins are incorporated in the die to ensure accurate location of the ejector plate.

In addition to these die members, there are other components and considerations that must be investigated by the die designer prior to detailing a die: die gates and runners, which are the paths through which the

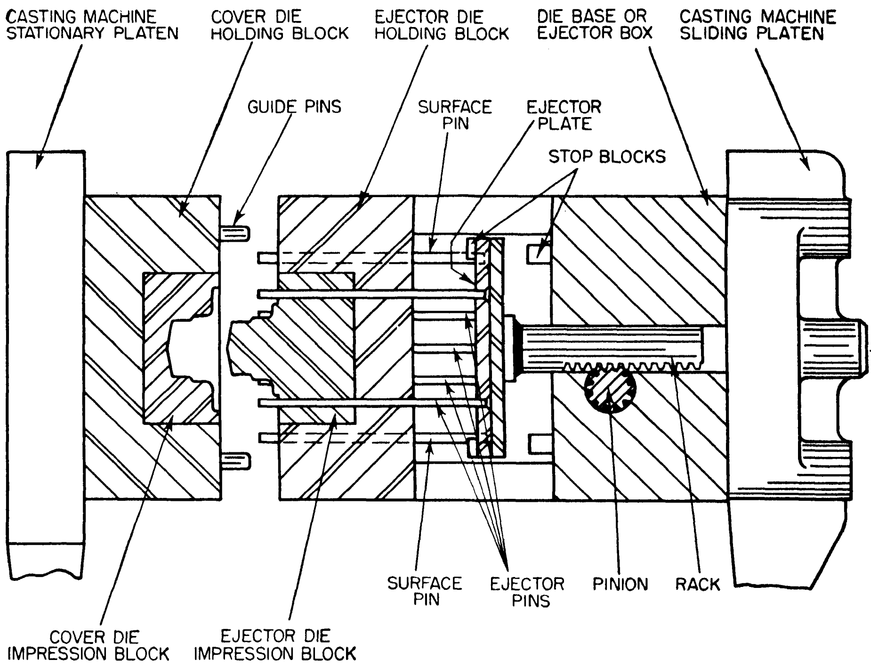


FIG. 2.1. Essential components of a simple die-casting die. Gates, cores, slides, vents, insert locators, and actuating mechanisms for movable die members usually must be added to this basic structure.

metal flows to all portions of the cavity; vents, which provide a path of escape for entrapped air and released gases; cores and slides, which form the hollow part or undercut sections of the casting; locks that hold the die halves in register when an irregular parting line is specified; mounting holes and brackets for all die components; and, of course, a means of actuating the movable-die components.

SPECIFIC DETAILS OF DIE CONSTRUCTION

Although it is desirable to have the parting line of the die in one plane for simplicity of design and ease of manufacture (see Chap. 4, Design of

Die Castings), many dies must be constructed with irregular faces or parting-line surfaces. This is necessary so that an irregularly shaped part can be cast without producing an undercut. Several examples of dies and parts having irregular contours at the parting-line surfaces are illustrated in Figs. 2.2 and 2.3.

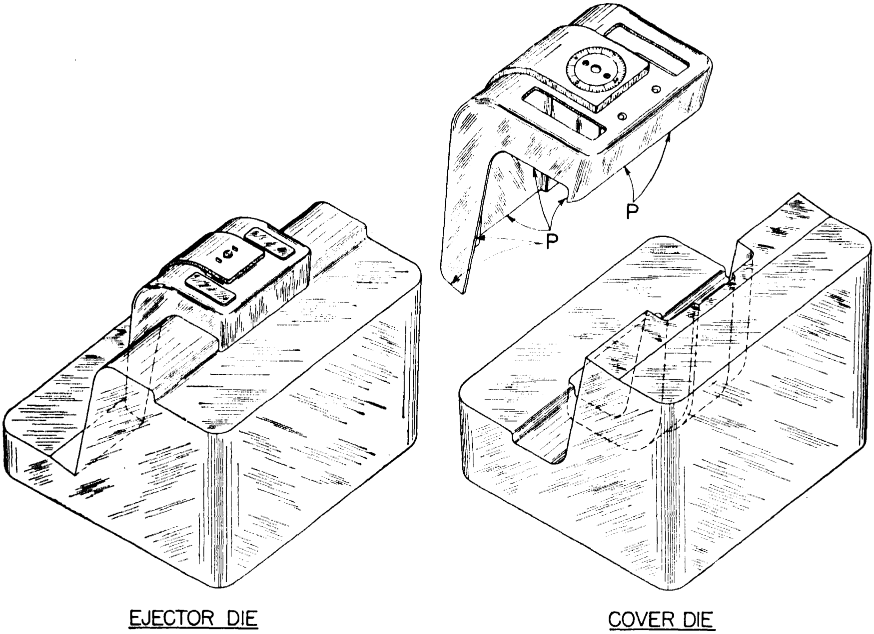


FIG. 2.2. Die halves having an irregular parting line for casting the part shown at the top. Although sometimes necessary, such dies are expensive to build.

The parting line is established in a die at the start of its design—even before doweling—in order to obtain an accurate fit of both halves of the die. After the parting line is established and machined and the die blocks are properly clamped together, the blocks can then be doweled to ensure perfect alignment of the two die halves. The disadvantages of an irregular parting line from the standpoint of the die caster are that (1) the contour of the cavity and mating surfaces of the die halves, being irregular in shape, are more difficult and costly to machine accurately; (2) since the contour of the flash on the casting also is irregular, more complex and costly trimming dies are required; and (3) the thrust caused by the irregular mating surfaces on the die necessitates careful die alignment and sometimes requires greater care in the design of the locking devices.

Several methods can be used to reproduce accurately any irregular parting surface. The one used most commonly is to duplicate the sur-

face of a model on which the desired contour has previously been developed. In most cases, the die blocks are rough-machined on a planer or heavy-duty shaper and then transferred to a milling machine or duplicator where the contour is finished prior to final "bluing" and fitting. Too much importance cannot be placed on this factor in die design, since

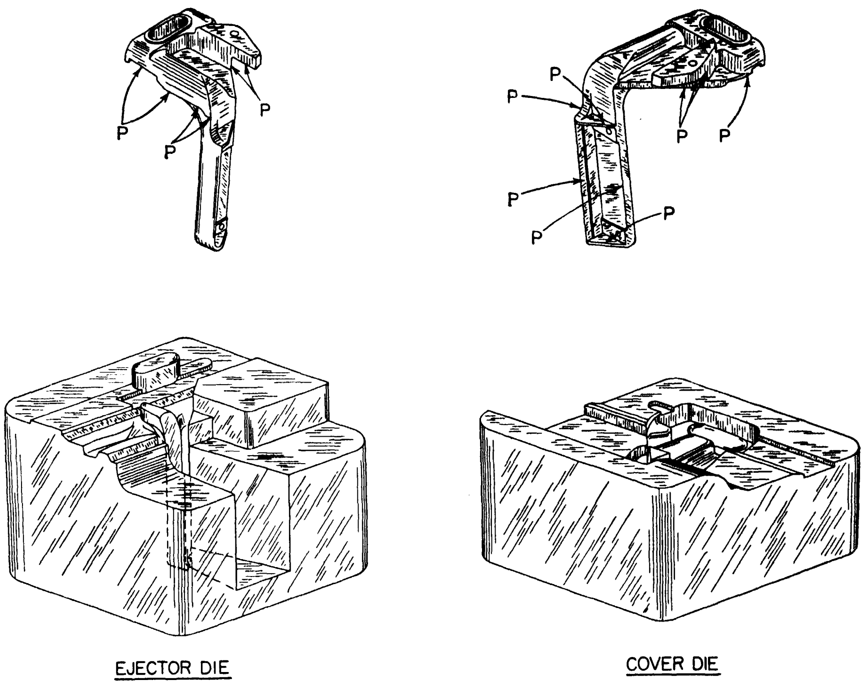


FIG. 2.3. Ejector- and cover-die halves for another casting, the design of which also necessitates use of a die having an irregular parting line. The parting line on the casting is indicated by *P*.

the accuracy with which the parting line is made will determine the workability of the die when it is finished. Also, from this surface, many of the finished locations and sizes must be determined.

When planning such a parting line it is also necessary to incorporate a means of keeping the two halves of the die properly fitted together at all times when the die is in production. It sometimes becomes necessary, therefore, to add additional supports to keep these parting surfaces from shifting by instituting the use of holding locks, which prevent the die from having any side slip. These locks are usually constructed with a locating angle and are heat-treated to obtain the maximum amount of wear; it is apparent that a great amount of wear on such locking sur-

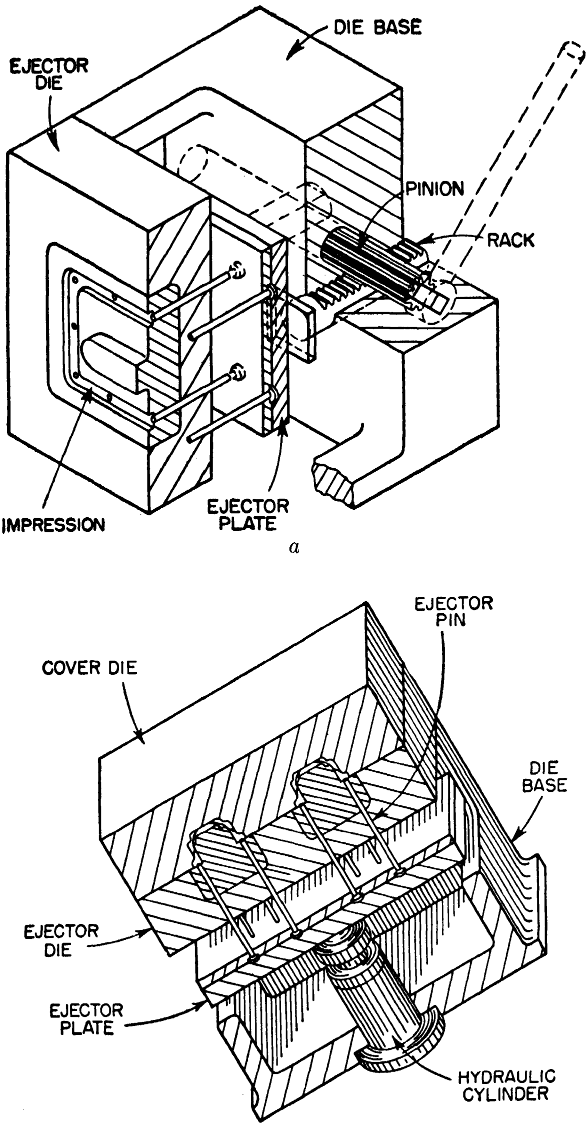
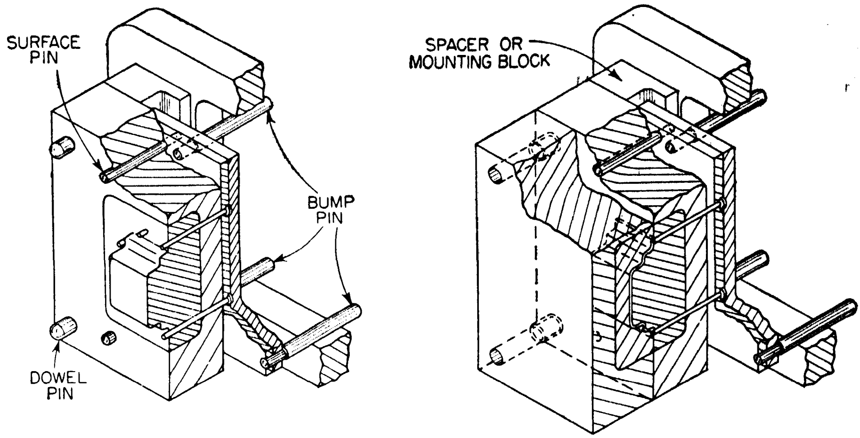


FIG. 2.4. Three common ways of actuating ejector plates: *a*, with a rack and pinion; *b*, with a hydraulic cylinder; or *c* (next page) by means of pins.



c

faces would cause a corresponding amount of side slipping between the two halves of the die.

Casting Ejection. As stated previously, one important part of die construction is a suitable provision for removing the casting from the die directly after it is formed.

Several methods of ejection are in common use, the one most generally employed being by means of ejector pins. Ejector pins are fashioned from accurately finished drill rod, with the head form thereon having the same shape as the head on small core pins. After suitable heat-treatment, the pins are secured in a double ejector plate. One of the plates is countersunk to hold the pins, while the other plate is fastened to the first to back up the heads of the pins.

The ejector pins should be so disposed as to push the hot casting properly and easily from its impression without distortion. Actuation of the ejector pins may be manually or automatically accomplished by means of a rack-and-pinion mechanism, by means of pins, or by manually or automatically operated hydraulic devices (Fig. 2.4).

Where small parts are involved, either their shape or their size makes the use of ejector pins or ejector pads impossible. Such a case is illustrated in Fig. 2.5. The use of ejector pins to eject this casting, which has very thin walls (not shown), would alter the shape of the casting considerably; therefore, a sleeve-type ejector must be used.

The water line *A* that enters the core *B* makes it necessary to split the ejector sleeve into two circular pieces *C*, since the core is stationary and the ejector sleeves must move. These sleeves are fastened in the unit

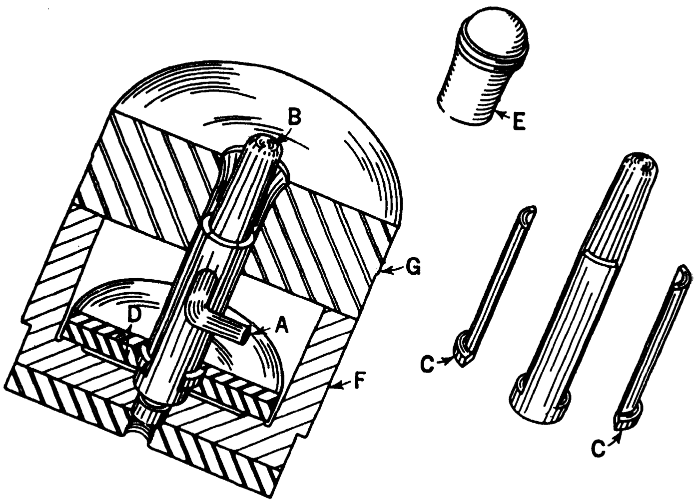


FIG. 2.5. Split-sleeve ejector die. This method of ejection was employed because the thin walls of the casting would have been distorted by pressure from ejector pins.

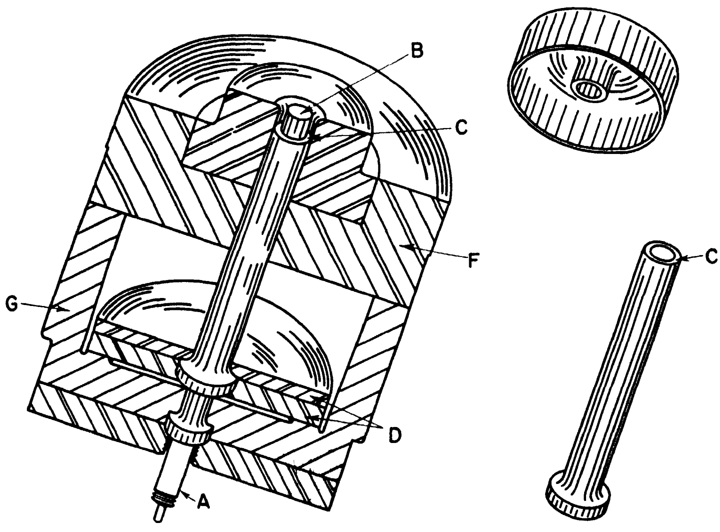
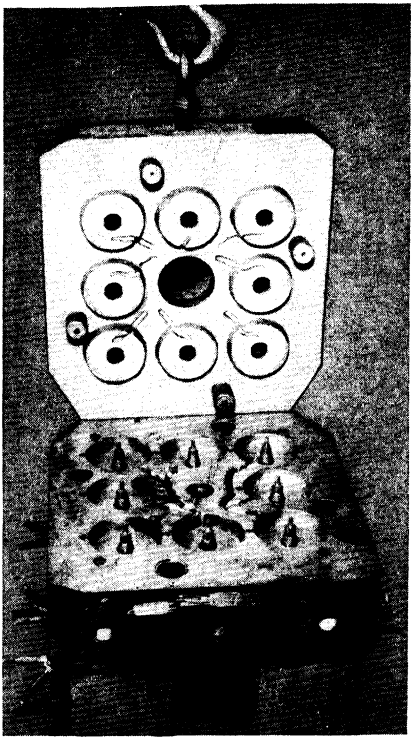
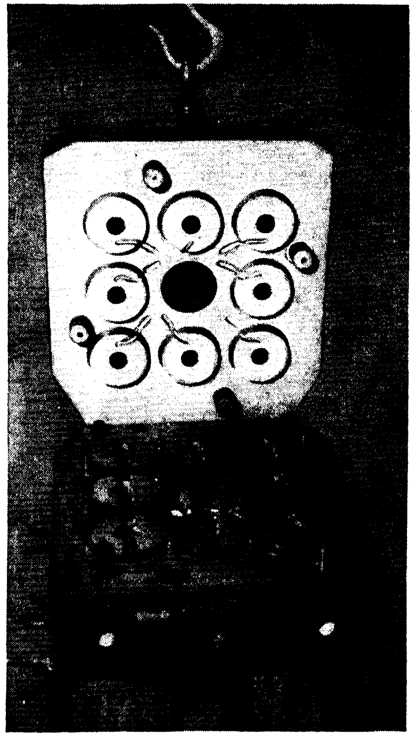


FIG. 2.6. Full-sleeve ejector die showing die construction and round flanged part that is cast in it.

ejector plates *D*, which are in turn moved up or down through the use of pusher pins (not shown). These pins bump against the master ejector plate in the master holding die and transfer the movement to the split sleeves which strip the casting *E* off the core and out of the impression.





Closed Open

FIG. 2.7. Die designed for angular ejection. Such dies often can be used to advantage for casting small parts with undercuts or threads.

The ejector die block *F* is fastened to the cast-iron bracket *G*, and the outsides of both pieces are ground to a standard size so that they may fit into the master holding die block.

A somewhat similar die is shown in Fig. 2.6, except that in this case a full-sleeve ejector is used. The part made in the die is shown at the top.

Angular-ejection Design. One die ejection system is known generally as *angular ejection.** The design centers around the use of a tapered impression block that is fitted in a tapered cavity in a master holding die.

* Developed and patented (Patent No. 2,366,475) by the Doehler-Jarvis Corporation.

This impression block is split in order to afford a means for ejecting the casting (Fig. 2.7). An additional advantage of this method of die construction is that it creates a vertical parting line on the part.

By the nature of the construction in having the split conical piece held and confined in a solid block, the so-called "die blow" is practically eliminated. An almost perfect parting-line match can be obtained, effecting concentricity between the multiple members of a die.

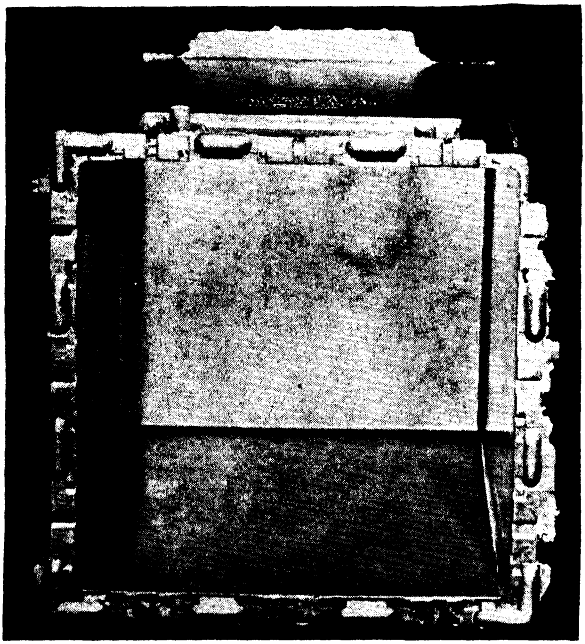


FIG. 2.8. Large, aluminum boxlike part with a flange that forms an undercut below the top surface. To cast this part in an ordinary die would require a complex system of slides.

Angular ejection is especially useful for parts such as are shown in Fig. 2.8. A small flange appears on all four walls near the open end of the aluminum casting. This casting could not be made in a conventional type of die because the flange or rib forms an undercut in the impression surface, preventing removal from the die. The die design, therefore, must be such that the vertical slides part at the corners and gradually pull away from the sides of the casting when the ejector plate is put into motion. The die for this casting is shown in Fig. 2.9.

Angled T slots or ribs A are machined in the back of the slides B, which form the vertical walls of the casting. After the metal has entered

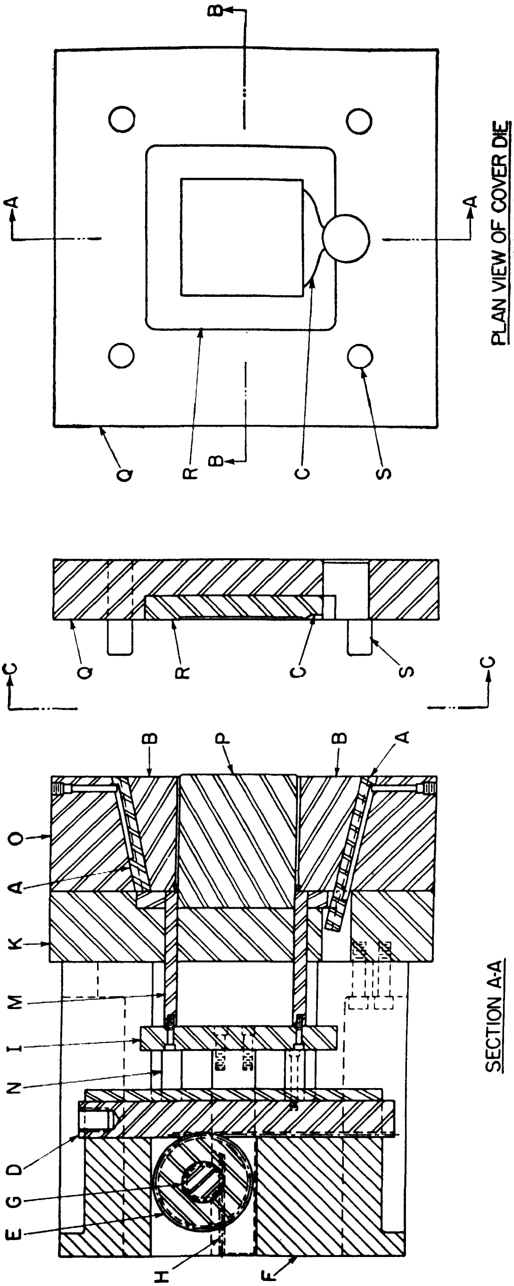
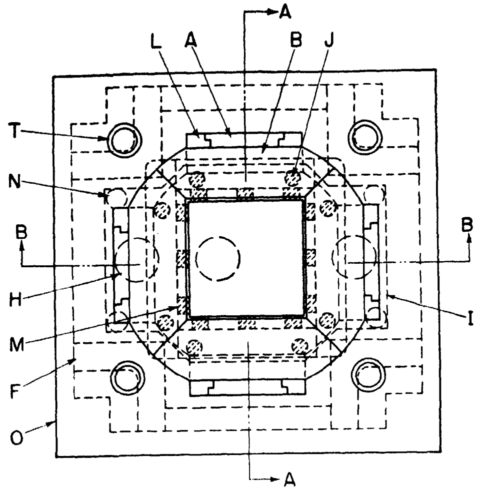
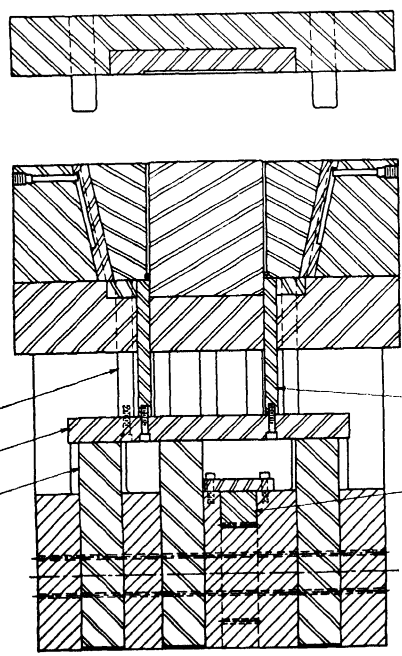


FIG. 2.9*a*. Angular-ejection die for casting the part shown in Fig. 2.8. Detailed plan and section views of the various components are shown here and in Fig. 2.9*b*.



PLAN VIEW OF EJECTOR DIE



SECTION B-B

FIG. 2.9b

the impression through gate runner *C* and the casting has solidified, these slides are moved toward the surface of the die.

The source of power needed to actuate the slides is supplied by a hydraulic cylinder (not shown) with a rack *D* attached to the end of its piston rod. This rack engages a bull gear *E* in the die base *F*, to which is fastened a pinion *G*. Because the casting produced in this die is so large, it must follow that the four slides constitute a heavy mass. A bull gear is used to increase the original power supplied to the die base by the hydraulic cylinder in order to move the slides with less effort. Three ejector racks *H* connected at one end to the ejector plate *I* mesh with the pinion and move forward toward the slides. Pusher pins *J*, which are fastened at one end in the ejector plate, protrude through holes in the backing plate *K* and contact the bottom of the slides, forcing them to move. As they move forward, they are spread apart by the angled T-slot guides *L*. When this movement first begins, the flange on the casting is still in the die impression. Gradually, however, as the slides spread farther apart, the casting is separated from them and is stripped from the large center core by square ejector pins *M*, which push against the bottom edge of the casting. These pins are of the same length as the pusher pins and are fastened in the same way to the ejector plate. After the casting has been removed from the die, the ejector plate moves back solidly against stops *N* so that all movable parts are again in position for making the next casting.

The movement of the four slides takes place within the large cavity in the ejector die holding block *O*. A backing plate fastened to the bottom of the holding block is used to mount the large square stationary core *P* in the center of the cavity. These two blocks, when fastened to the die base, form the complete ejector die or movable unit.

Cover-die holding block *Q* contains that portion of the impression *R* which forms the bottom of the casting. Guide pins *S* in the cover die and bushings *T* in the ejector die keep both halves of the die aligned to minimize mismatch at the parting line.

An assembly and an exploded view of another angular-ejection-unit die are shown in Fig. 2.10. Within the die base attached to the master holding blocks is a master ejector plate (not shown). Three pusher pins *A*, one of which is shown, attached at one end to the unit ejector plate *B* move upward and start the action. Three separate plates *C* fasten to the unit ejector plate and form T slots in which the angular impression blocks *D* slide. As the unit ejector moves upward it forces the angular slides to move horizontally in the T slots *E* at the same time as the slides move upward in the vertical T slots *F*. Thus, the sliding impres-

sion blocks spread apart as they move upward and free the casting from the die.

The flanged end of the core G is seated in the unit ejector plate but does not move along with the slides. The end H of the core is somewhat longer than usual to allow the casting to slide on it until the sliding impression blocks spread far enough to free the casting I.

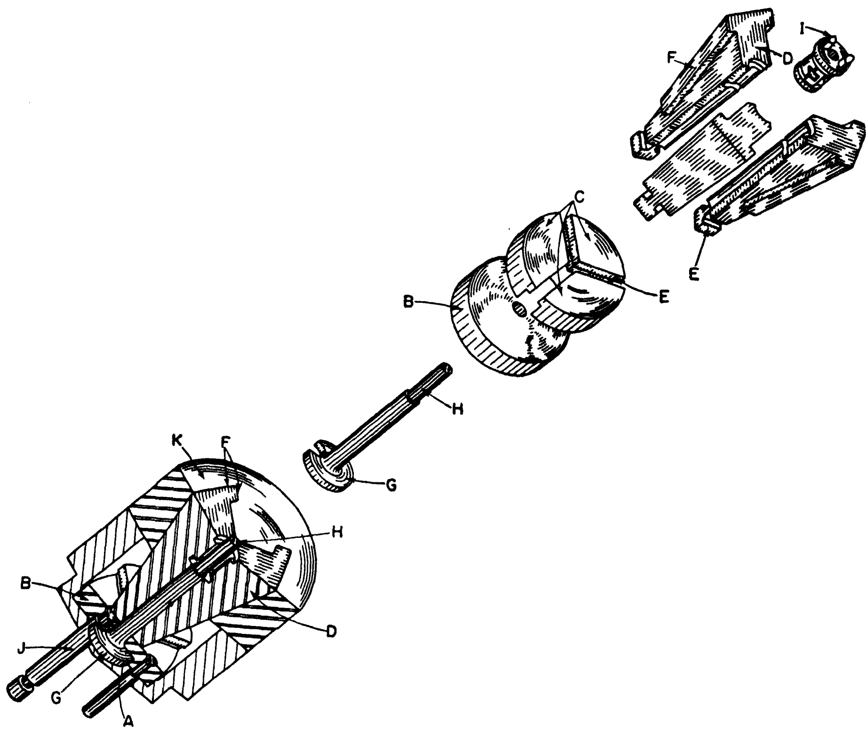


Fig. 2.10. Exploded and assembly views showing how an angular-ejection die operates.

The pullback pin J, which is connected at one end to the master ejector plate and at the other end to the unit ejector plate, returns the slides and core almost to casting position. The cover die then closes against the surface of the die K and forces the moving components back solidly against stops, ready for casting.

Cores, Slides, and Loose Die Pieces. *Cores.* In die casting, a hole of almost any shape can be cored. Round, square, rectangular, oblong, and polygonal holes with keyways or other shaped slots, as well as splined and geared holes, can be formed in a casting.

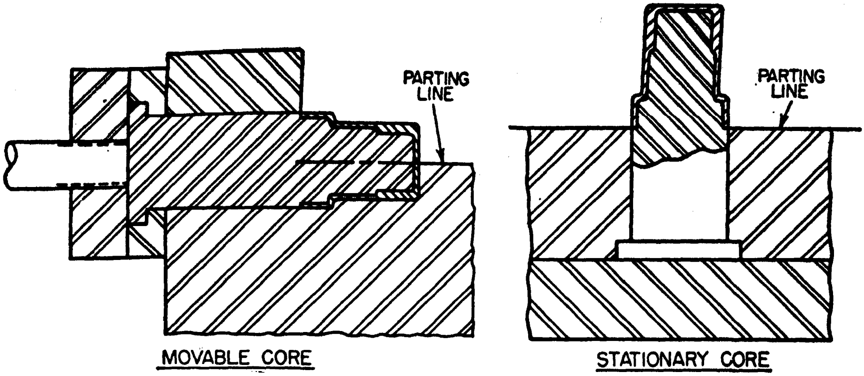


FIG. 2.11. Typical movable and stationary cores. Stationary cores are generally satisfactory only when the axis of the hole to be formed is at right angles to the parting line of the die.

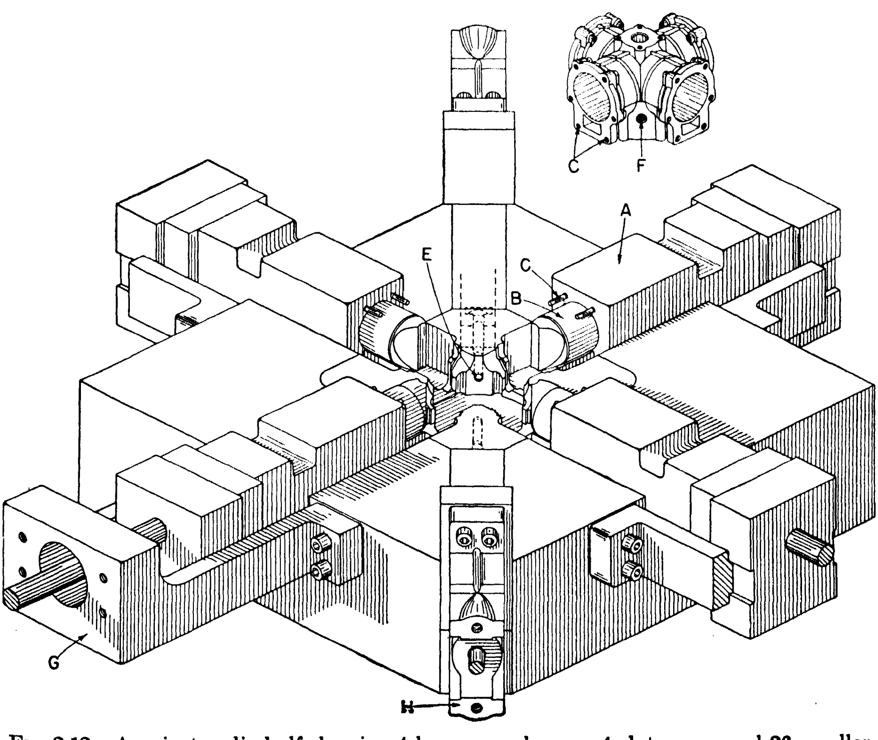


FIG. 2.12. An ejector-die half showing 4 large round cores, 4 slot cores, and 26 smaller diameter cores in position for ejecting the casting, top.

In addition to providing holes, slots, and recesses that minimize or totally eliminate the need for machining, the use of suitably designed cores helps to save weight and is a means for producing uniform sections, which in turn substantially aids castability and the production of sound castings.

Cores may be stationary or movable (Fig. 2.11). Stationary or fixed cores are used primarily when the axes of the holes are at right angles

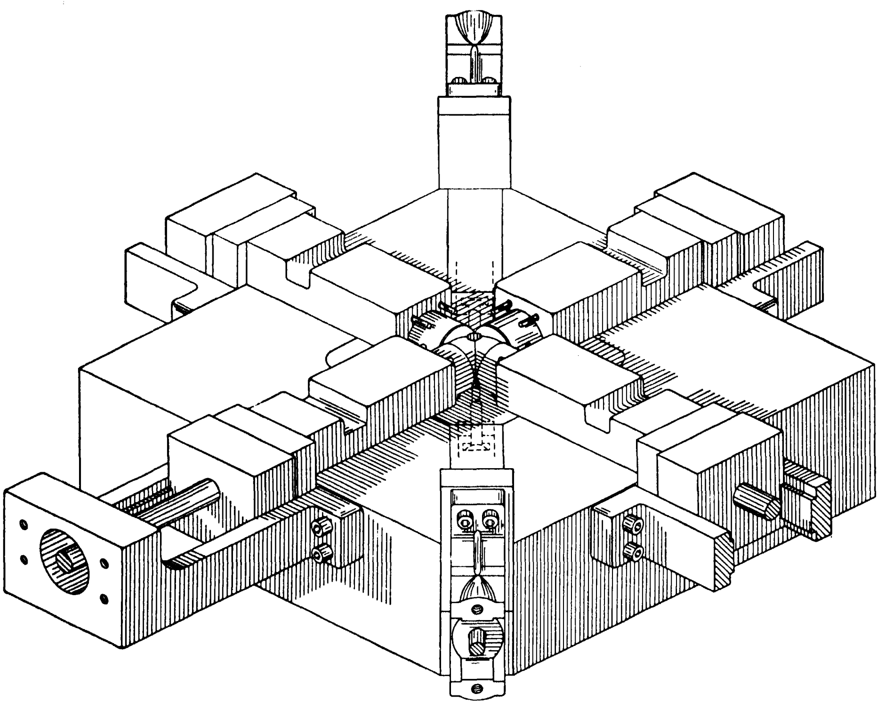


FIG. 2.13. Ejector die with all cores in position to make the shot.

to the parting line of the die. Movable cores are those having axes parallel to or at any angle with the parting line. Movable cores must always be withdrawn from the casting prior to its removal from the die.

A very interesting die having a total of 34 cores—4 round cores, 4 slot cores, and 26 small-diameter cores—is shown in Figs. 2.12 and 2.13. This die illustrates very well what is probably the most common type of movable core: the *straight-sliding core.* Each of the four large movable core slides *A*, placed 90 deg apart, has a large round center core *B* that forms the large hole in the casting. There are also four small cores around the large-diameter core, and two more, *C*, at the bottom of the

squared section beneath the large core. A core that makes the rectangular slot is also attached to this block. Two round cores *E* mounted parallel to the face of the die and at 45-deg angles to the large sliding blocks form two holes, one of which is shown at *F*. All the sliding blocks

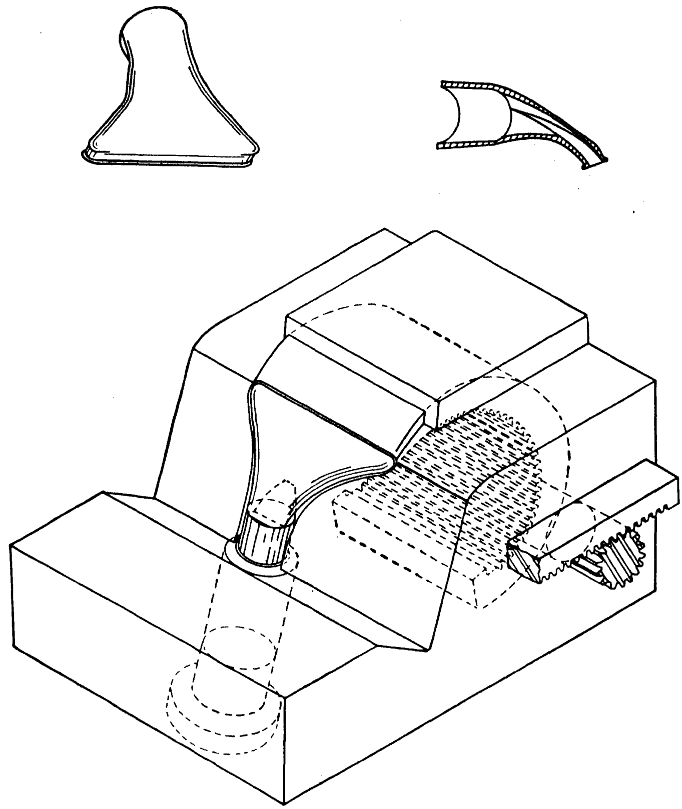


FIG. 2.14. Another type of movable core is the rotary type. This unit, which is used to cast the nozzle for a household vacuum cleaner, is used because the hole in the part is cored on an arc.

are actuated by hydraulic cylinders that are mounted on the brackets *G* and *H*, each core block having its own cylinder.

Rotary Cores. Rotary cores, such as the one shown in Fig. 2.14, are those that are pulled on an arc. While expensive to build, they sometimes provide the only possible method of coring a casting that has an internal radius of curvature. Although rotary cores are not too common, since it is often possible to design the casting in such a way that they are not needed, they are an acceptable and proved type of coring mechanism.

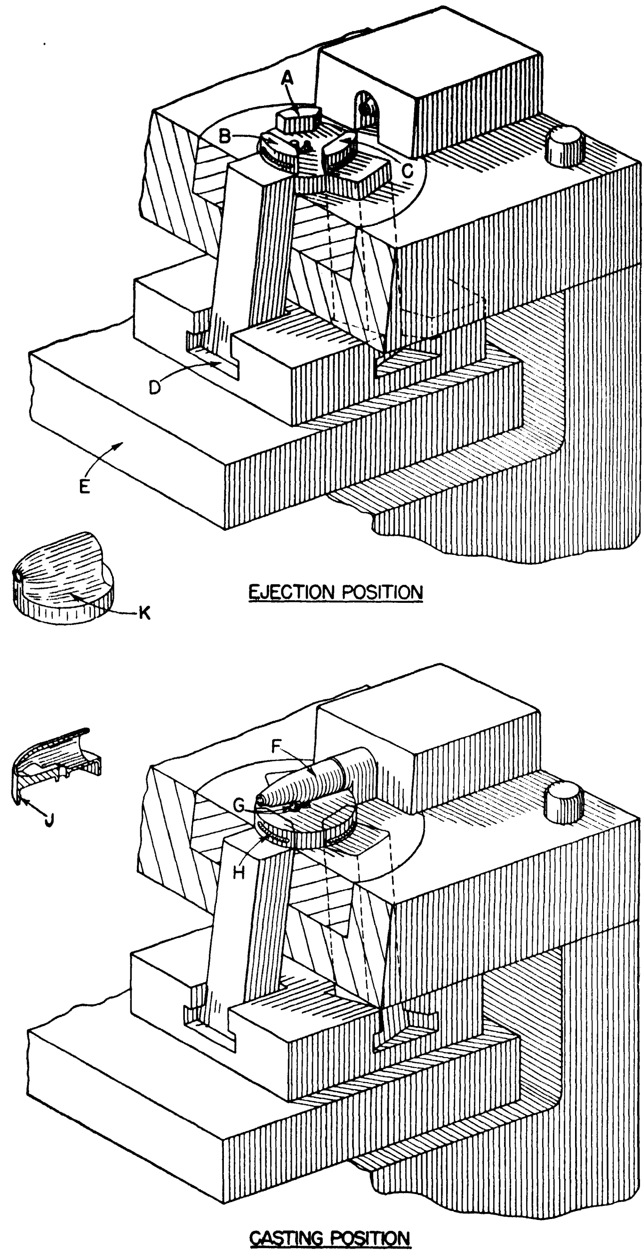


FIG. 2.15. Ejector half of a die-casting die in which a collapsible core is utilized to cast internal threads.

Collapsible Cores. Another form of movable core is the collapsible core. A collapsible core is practical only when the casting cannot be produced more cheaply by using loose die pieces or by machining the hole. This type of core usually leaves flash on the inside of the casting, which is sometimes hard to remove inexpensively. The die is also rather costly to construct and frequently requires substantial maintenance.

A die designed to cast an interrupted internal jar thread by means of a collapsible core is shown in Fig. 2.15. The upper drawing shows movable core parts *A, B,* and *C,* which contain the thread impressions. They are set on an angle so that they form a smaller diameter to clear the internal cast threads and eject the casting. These movable core parts slide in angular slots cut through the die block and impression block and are moved vertically by the plate *D,* which is fastened to the ejector plate *E.* Plate *D* is provided with three T slots to allow the core parts to move horizontally, thus compensating for the vertical movement of the pieces that takes place at the same time.

The lower drawing shows all cores, including the horizontal sliding core *F* and the two stationary cores *G,* in the proper position for making the casting. The internal thread impressions *H* are cut into each of the three cores at the correct helix angle and are shown on the cross-sectional view at *J.* Part *K* is the completed casting made from this die.

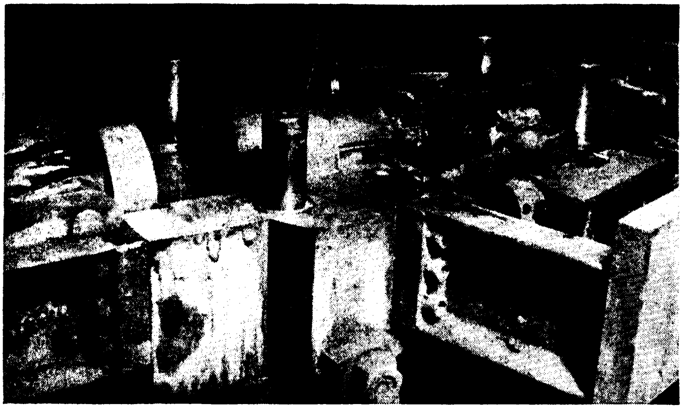
Hinged Cores. In some cases, notably in the construction of dies for magneto housings where inserts are used to a great extent, what are known as *hinged cores* have been developed.

When durable wearing surfaces are required in certain sections of the casting that may function as a bearing surface, a steel or brass insert is cast into position. In certain instances, the face on which the insert is positioned is inaccessible to the operator when placing the inserts before making the shot.

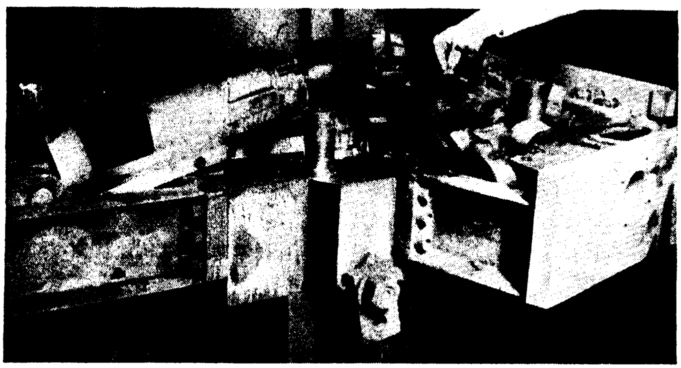
Such was the case with the die shown in Fig. 2.16. Here is an instance in which the core face bearing the inserts is hard to get at. The core was designed so that it is fastened on the header block by means of a hinge. When the die is in an open position the operator pulls the slide away from the die at an angle, thus obtaining free access to the face on which the insert must be placed. After the inserts have been placed, it is pushed into position on the die and the slides are pushed home. This is another example of ingenuity in accomplishing a purpose.

In some cases the castings are of such a depth that the limitations of the opening of the machine will not permit the removal of the casting in the ordinary method. To overcome this, the ejector die is designed with a hinge so that it can be swung at an angle to protrude between the machine bars and the casting, which then is ejected from the core.

Spiral Cores. The twin-impression die in Fig. 2.17 is used to cast spiral bevel gears. Because of the curve and angle on which the teeth are set in relation to the pitch-core radius, it is necessary to use a core that, when revolved, follows the same curve and angle of the gear teeth in



a



b

FIG. 2.16. Die with hinged cores in the casting position (*a*), and with the cores lifted up to facilitate placement of inserts on the holders (*b*).

order to remove the castings from the impressions. The cost of constructing this die compared to the cost involved in constructing a conventional die is rather high.

In the ejection view, the sliding plate *A* is in position under the castings which have finished the upward spiral motion necessary to free them from the impressions. The cores have already moved in a reverse spiral direction down into the casting position, leaving the castings resting on

the sliding plate. The thin section of the gate B bends enough to allow the castings to "screw" out of the impression, thus completing the ejection cycle. Sliding plate A is moved by a hydraulic cylinder which is fastened on the end of bracket C. The end of the piston rod D is screwed into the sliding block E, which moves along two grooves F. A long handle is pivoted at G and goes through a rectangular slot into a similar one in the sliding plate.

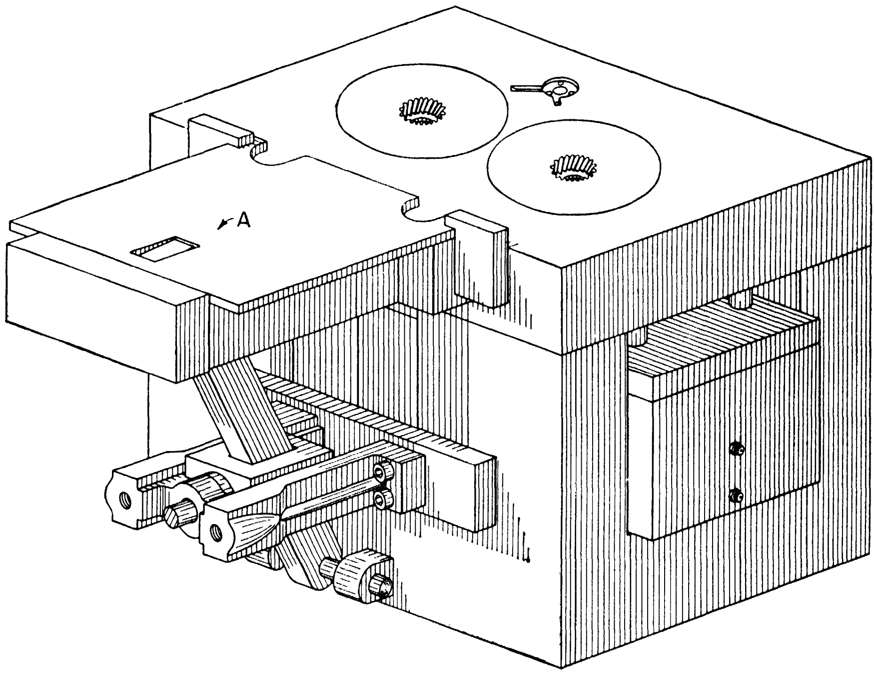


FIG. 2.17*a*. Die with spiral cores used to cast bevel gears, in the injection position.

As seen in the cross-sectional view, the ejector plate A moves in a vertical direction and is actuated by the racks and pinions in the die base. Two keys, B and C, that fit into the two spiral slots D and E in the core guide the radial movement of the core as it is forced to move vertically by the ejector plate A. The double-row ball bearings at F and the two sets of ball thrust bearings G keep the core concentric with the pitch diameter of the gear impression H. The retainer at J is used to hold the grease down in the ejector plate, thereby keeping the bearings lubricated; without this retainer, the grease would work itself out of the bearings due to the rotation of the core and might cause serious damage to the die.

Core-actuating and Locking Devices. Selecting the best method of core actuation, as well as a suitable mechanism for locking and holding the cores in the desired position during the casting operation, influences to a great extent the success of many die-casting applications. If the core is difficult to "pull," the rapidity with which a shot can be made is decreased. If the core is pushed out of position by the pressure of the molten metal as it enters the die, the casting must be rejected.

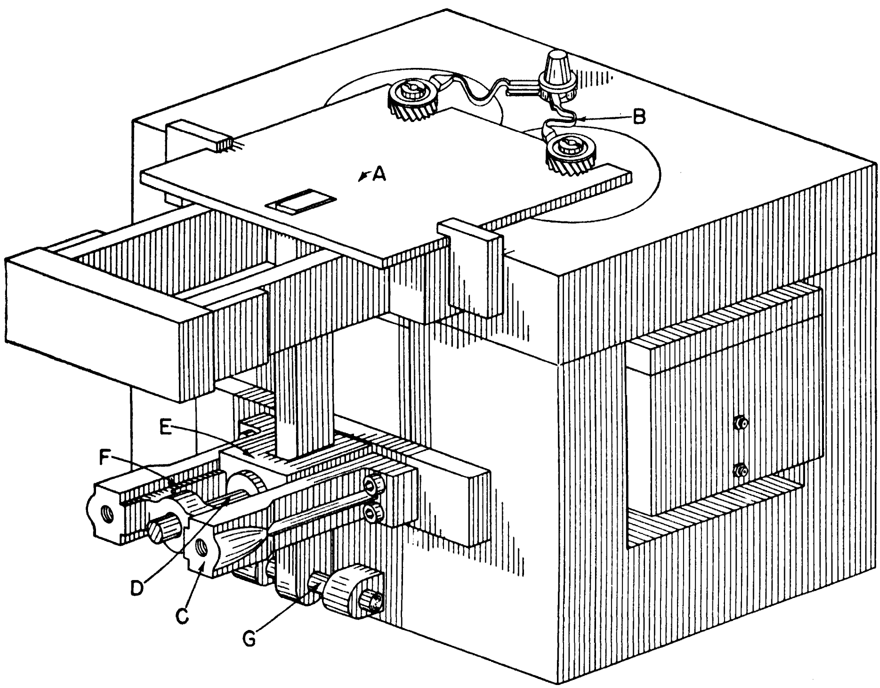


FIG. 2.17*b*. Same die as shown in Fig. 2.17*a*, in the ejection position. The casting is on top.

Some of the common mechanisms, *core pulls,* that are used for core actuation are illustrated in Figs. 2.18 to 2.21.

Rack-and-pinion Core Pull. In the rack-and-pinion core pull (Fig. 2.18), a rack (not shown) is attached to a hydraulic actuating cylinder and is engaged with the pinion *A*. A hole is bored into the core backup block *B* to hold the pinion, and the action received from the hydraulically operated rack transfers the movement to two stationary racks *C* pressed into the ejector die *D*. These racks serve two purposes: (1) to act as guide pins for the core backup block, and (2) to move the block. To the backup plate is attached a core plate *E* in which the cores *F* are secured.

These cores are kept in perfect alignment by the use of core bearing blocks *G*. The sliding cores move through these blocks on their way into and out of the die.

The locking block *H* is attached to the cover die *I*, and when the two halves of the die close, the two tapered surfaces *J* on the locking block

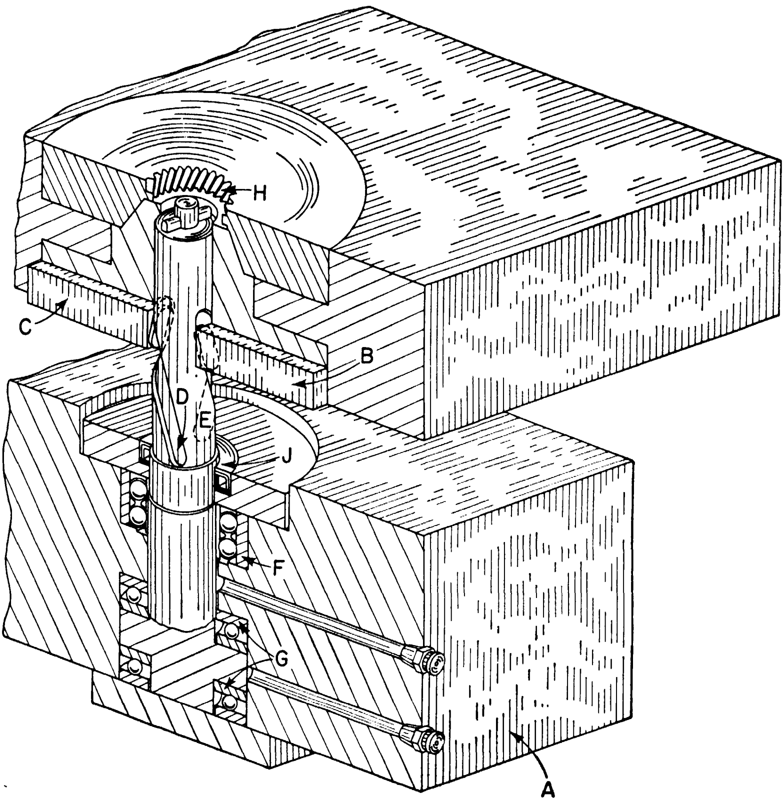


FIG. 2.17*c*. Sectional view of the spiral-core die in the injection position. When the core is retracted after the shot, it turns so that it follows the same curve and angle as the formed teeth.

and the core backing block slide over each other. The already advanced cores are then locked in position and cannot move back when metal is forced into the impressions.

Pin Core Pull. A somewhat simpler type of core pull, which usually is confined to smaller dies, is the pin-actuated core pull (Fig. 2.19). When the two halves of this die are closed, the long dowel pin *A* secured in the locking block *B* on the cover half *C* of the die engages in hole *D* in the

core backup block *E*. The dowel pin, because of its length, engages the angled hole as the two halves of the die begin to close. The cores are fully advanced and locked into position, therefore, when the dies are completely closed.

Two guide pins *F*, one end of which is pressed into the ejector die block *G* and the other end of which is fastened to plate *H*, allow the backup

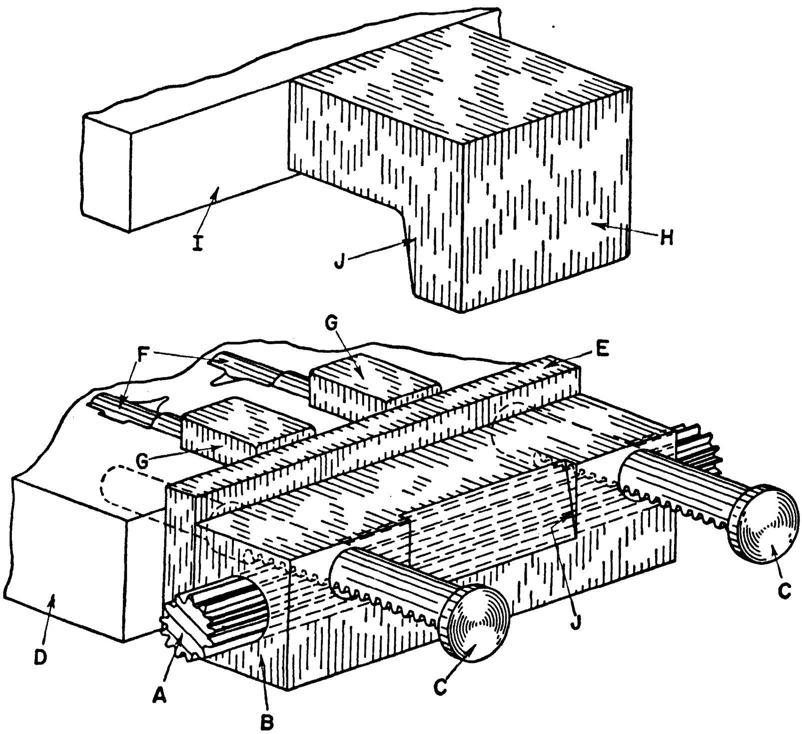


FIG. 2.18. Rack-and-pinion core pull. Not shown is the hydraulically actuated rack that engages the pinion *A*.

block to slide in perfect alignment back and forth as the cores move into and out of the impression. The spring *I* located between the two guide pins places a slight tension on the dowel pin *A* when the pin is in contact with the hole in the backup-plate block, thus reducing the amount of play between the two. The sliding cores *J* are secured at one end to the core plate *K* and move through a core bearing block *L*, further ensuring their alignment.

When the die is closed, the tapered surfaces *M* of both the locking block and the sliding backup are tight against each other, and no backward movement of the block can take place when the shot is made.

Hydraulic Core Pull. The use of a hydraulic core pull is also one of the more common methods of pulling sliding cores in a casting die.

The hydraulic core pull in Fig. 2.20 shows the cores as they appear when fully advanced in the ejector die *A*. The hydraulic cylinder *B* attached to the core-pull bracket *C* supplies the action by which the cores

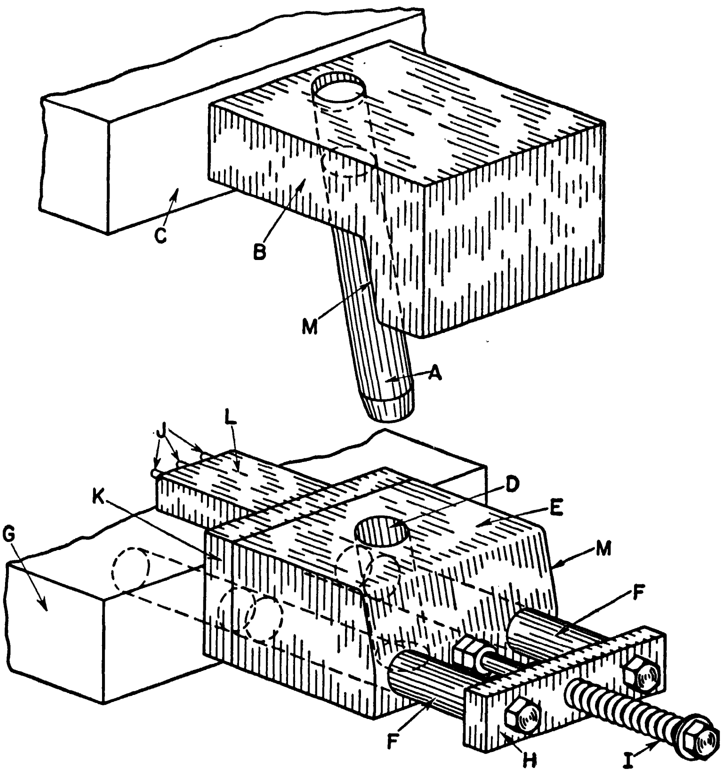


FIG. 2.19. Pin-actuated core pull, which is a somewhat less complex device than the rack-and-pinion type.

are advanced or withdrawn. Sliding core block *D* is connected directly to the piston rod *E* of the hydraulic cylinder. Cores *F* slide through core bearing block *G* and fasten in the sliding block. The core bearing block keeps the cores in proper alignment through their cycle of movement.

As the dies begin to close, the hydraulic cylinder moves the cores in position for casting so that by the time the dies are completely closed the cores are already fully advanced.

When the external lock *H* attached to the cover half *I* of the die moves down over the sliding core block, the tapered surfaces *J* on both sides

of the locking block wedge between the sliding block and a stop *K* and force the core pull to lock itself, thereby keeping the cores from moving back when the pressurized metal enters the die.

Cam-actuated Cores. Occasionally cores are actuated by cams or cam plates. For example, a two-impression die with which four holes are cast in the cylindrical walls of a spline collar casting through the use of

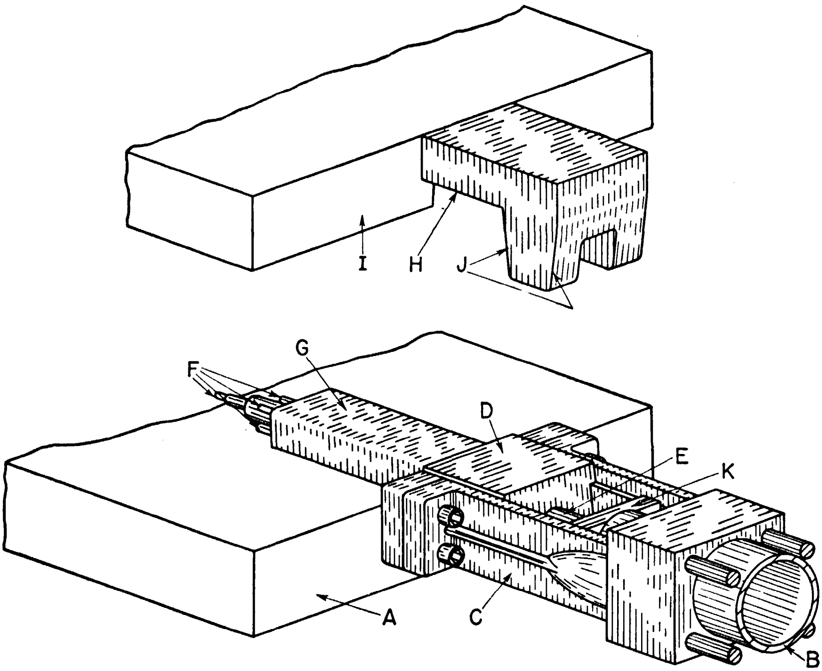


FIG. 2.20. Typical hydraulic core pull showing the hydraulic cylinder *C* that is used to advance and retract the cores.

sliding cores is shown in Fig. 2.21. These cores *A* slide in four different directions on a plane parallel to the face of the die and are actuated by cam plates *B*. Four cam slots *C* designed to slide the cores in place and lock them are milled into each plate. The right-hand cam plate is rotated by a lever attached at *D*, which is actuated by a toggle arrangement mounted on the side of the die. Spur gear teeth on the rim of this plate mesh with gear teeth on the rim of the left-hand plate. Thus, the two plates rotate in opposite directions in unison, sliding the cores in or out as desired. The impression blocks *E* are mounted to the flanged base plates *F* and set into holding die *G*.

The cross-sectional view of the assembly at the bottom of the drawing shows all the pieces of the die in their proper relationship and position.

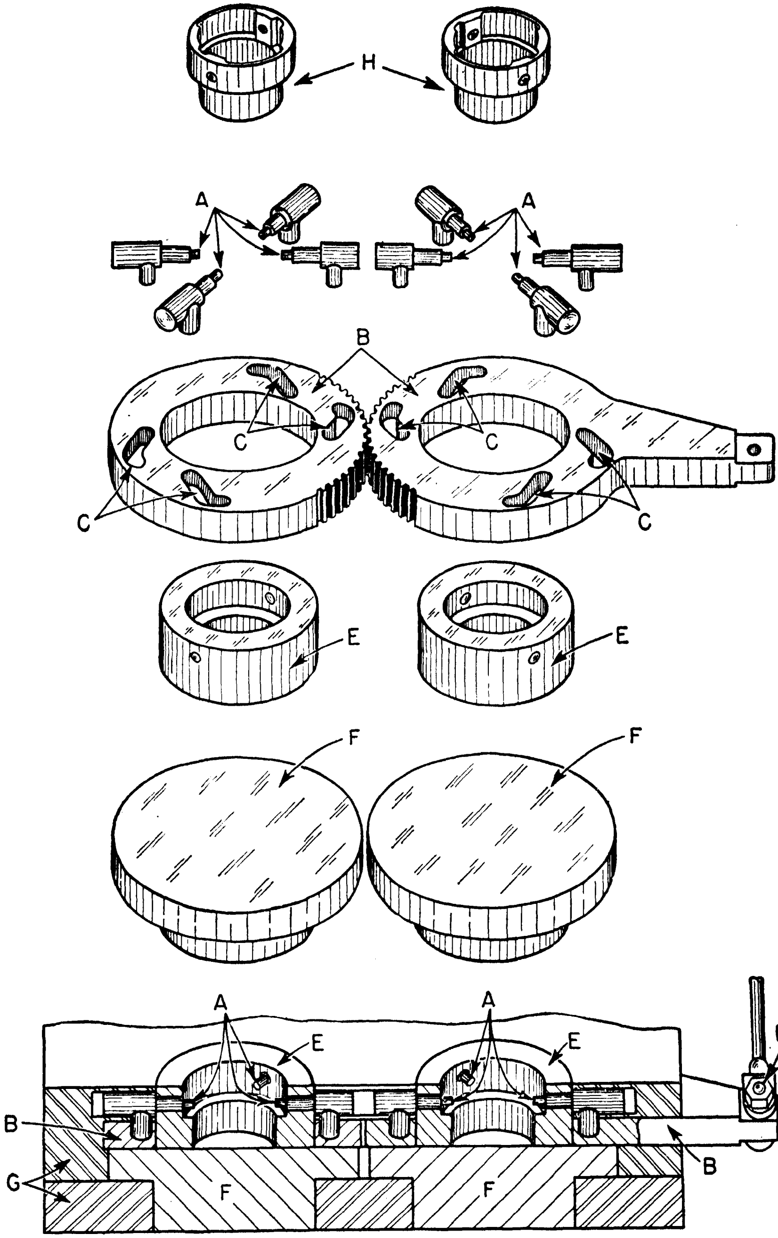


FIG. 2.21. Exploded and assembly view of a spline-collar ejection die having sliding cores that are moved in different directions at the same time through the use of cam plates.

Cores are advanced and in the position they assume before metal is ejected into the die.

Slip-plate Die Base. Frequently it is necessary first to withdraw cores which have been placed vertically in the ejector die, parallel to the position in which the ejector pins operate, before the casting is ejected, since the shrinkage of the metal around the core pin would tend to bend the casting if the ejection were attempted before withdrawing the cores. A favorite means of withdrawing these cores, especially in the case of multiple-impression dies, is what is known as the *slip-plate die base.* The technique is as follows:

The ordinary die base is a massive boxlike affair of cast iron with the legs cast at the four corners; it must have sufficient opening to provide movement for the ejector plate and be thick enough at the bottom to support the racks which operate the plate. The top of the legs and the back of the casting are machined parallel.

To make a slip-plate base, a 2-in. flat plate is doweled to the bottom of the base with enough freedom to allow the plate to slide away from the base a distance of from 1.0 to 1.5 in. The core-plate racks are fastened to the sliding plate. When the die is fastened in the casting machine, the base is held secure by fastening the screws to the plate, allowing the plate to move the distance provided before the rest of the ejector die follows the motion of the machine. The core plate is thus locked in position while the shot is made and withdrawn from the die when the machine is opened before the casting is ejected, thus making the motion automatic.

Taper Slides. When sliding side cores are encountered, the slides should be made with a working taper (Fig. 2.22). The amount of working taper need be a matter of only a few degrees, but it must be sufficient to produce a breaking or freeing action as soon as the slide has been pulled. Experience has taught that if a slide is made straight and does not have this working taper on all the hard pulling surfaces, the slide will gall or cut fast and thereby prevent efficient operation of the die. This taper must be accurately fitted so that when the slide is in the casting position, the metal is sealed from the bearing surface. A great deal of care and accuracy, therefore, should be used in its making. Care also should be taken to ensure that this fitting is properly done prior to finishing the impression work so that the matching parts can be squared and aligned after the slide is properly fitted and in position.

The success of any side-core mechanism always depends upon the care with which these cores are made and fitted to the die. The slightest amount of leakage caused by an improperly fitted slide can cause no end

of trouble and can even damage the die to the point of making it unsatisfactory for use.

Core and Slide Locks. After these tapers have been developed and fitted, it is equally important to provide effective means for keeping the slides in the casting position. One of the most effective means for doing this is by the use of an internal wedge lock near the casting area. These locks, like the slides, are made with a few degrees of taper and are accurately fitted to a matching taper in the slide proper. Final fitting

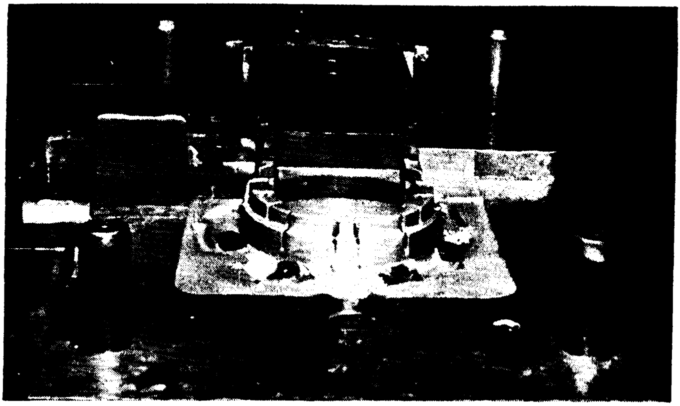


Fig. 2.22. Sliding side core having a working taper. The slide is in the working position.

should be with the die open, allowing about 0.015 in. to provide an absolute locking action when the die is finally closed on the casting machine.

Too much attention cannot be paid to any angular fit, whether it be on the slide proper or in the locking used to hold the slide in its casting position; all such surfaces must be carefully machined, ground, and finally blued to fit, if maximum efficiency is to be expected from any given die. To understand the application of the internal wedge lock better, bear in mind that various other types of locks are employed on the different types of dies (Fig. 2.23), such as the ordinary wedge lock, the double wedge lock, and the combination pull pin and wedge lock.

Not all the slides or cores are operated hydraulically. Sometimes, as in this case, steel pins are securely anchored at right angles to the side of the die on which the core or slide header operates to keep it in perfect position. When the cover and ejector die are in the closed position the steel lock is fastened to the cover die in which the angle corresponds to the angle on the core header block on the ejector die. The angular pinhole is drilled through both the cover lock and ejector header block in

perfect alignment, with a free fit in the ejector block and a drive fit for the pin in the cover lock, at an angle 2 deg less than the angle on the lock itself to prevent binding.

When the die is opened the pin will slide in the angular hole, withdrawing the core from the die. This combination serves both to withdraw the core and to lock it in position when the die is closed. The spring attached to the header block serves to keep it from falling closed so that it is always in a position for the pin to enter when closing in preparation for the next shot.

FIG. 2.23. One type of wedge lock, which serves to hold the cores securely in position and to prevent side shift between the cover and ejector die.

The double wedge lock is employed when hydraulic movement of the core header is used. In these instances it is necessary to build a frame around the core header in which the core header slides and on which the hydraulic cylinder is mounted.

When an internal wedge lock is used the lock is inserted close to the casting surface of a large slide or core on the parting line, and the core cut out to match. In many cases the lock may be fashioned and left standing in the solid on the cover-die block when the parting line is prepared, thus eliminating any possibility of spring.

A still different method of locking a side slide is illustrated by the die shown in Fig. 2.24, although in this case the slides are not used to core the casting. Each of the two slides contains a segment of a raised circular section with tapered sides called a *ring lock*, *I*. When the slides are closed the segments form a complete circle with the exception of the square slide at the top of the die, which forms one end of the casting. A similar tapered circular section, except that this section is depressed, appears in the cover die *J*. When all the slides are in the casting position, the cover die closes over them and holds them in place.

A third slide at the top of the die contains a tapered hole in which the internal lock *K* fits, locking the slide in position for casting. The slide, of course, is moved into casting position by a hydraulic cylinder mounted on the hydraulic pull frame *G*. When the die is closed the internal lock merely keeps the slide from moving back while the shot is made.

The casting made in this die contains two steel inserts called *pole shoes, L*. These inserts have to be placed in the die by hand and held in position by mechanical means until the die closes and the shot is made. The inserts, which are placed in the cover die, fit around a circular portion of the die impression block *M*. Two blades or pole-shoe retainers *N* mounted in the retainer block *O* move down around the inserts and hold them in position until the die closes. Then the pole-shoe retainers retract to the position shown in section *C-C* of the cover die, and the shot is made.

A cam *P* supplies the power with which to move the pole-shoe retainers and the retainer block. A hydraulic pull frame *Q* is mounted to the top of the cover die. In this frame a square block of steel or cam stop *R* slides on two grooves. Cam *P* is fastened to this block at one end and slides through a round hole in the cover die. The other end of the cam is machined away to leave four flats and two raised square ears that fit in two grooves in the retainer block, as shown in section *C-C* of the cover die. The ears, which are left standing, are machined on an angle so that as the camshaft moves backward and forward, the retainer block moves up or down, thus retracting or advancing the pole-shoe retainers as the case may be.

Aluminum alloy forced from the shot cylinder enters the ejector die through the sprue plug *A* and travels into the impression through the gate runner *B*. Two slides *C* mounted on the sides of the ejector-die block *D* form the outside wall of the impression. These slides are fastened to slide backing plates *E*, which in turn slide back and forth on two guide pins *F*. One end of the guide pin is pressed into the die block and the other end fits into the hydraulic pull frames *G*. A hydraulic core-pull cylinder moves the entire slide into the impression for casting and then back solidly against stops *H* to clear the slides for ejecting the casting.

Water lines *S* serve the slides, the stationary-die blocks, and the impression blocks in both halves of the die with water to keep the die at an efficient temperature for making good castings. The ejector pins *T* slide through holes in the ejector die and are fastened at one end to the ejector plate *U*. The other ends of the pins contact the casting and push it from the impression. Two racks *V*, welded to a flange plate which is bolted to the ejector plate, and a pinion *W*, set in a hole drilled in the

die base *X*, actuate the ejector mechanism. Four dowel pins *Y* set in the ejector-die holding block and four bushings *Z* in the cover-die

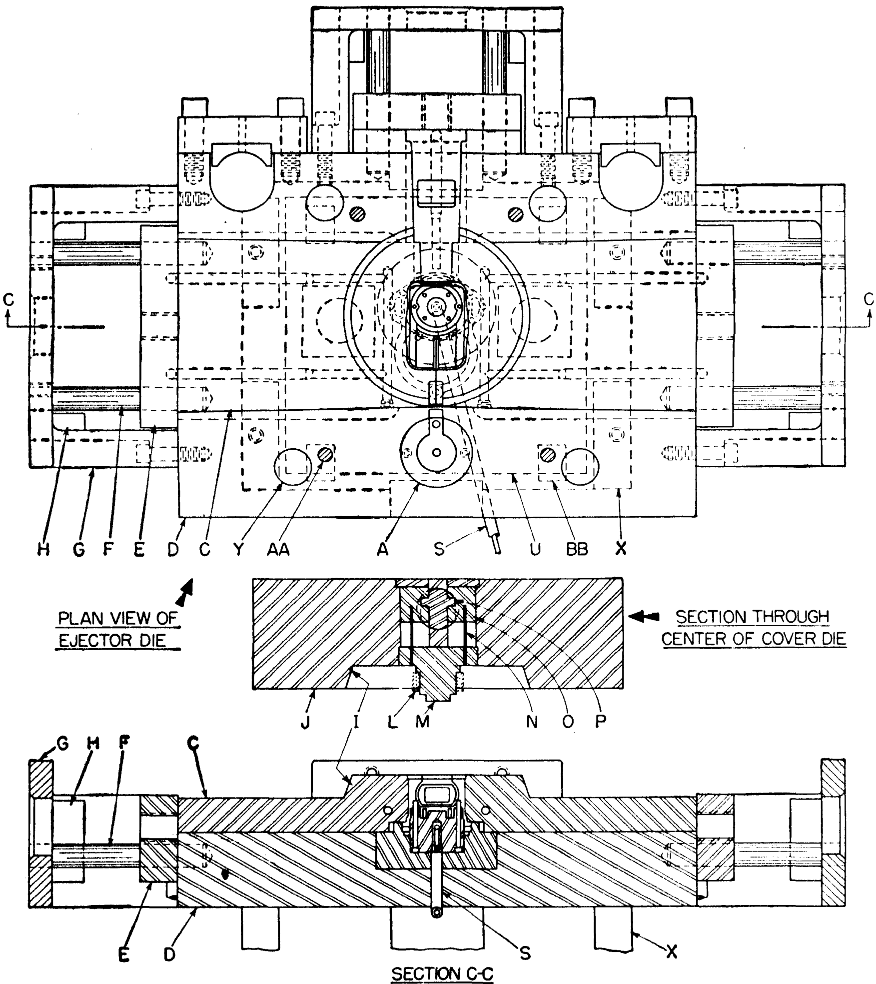


FIG. 2.24*a*. Plan view of ejector die and section views of cover and ejector die in which a ring lock *I* is used to hold side slides in position during the casting operation. For part legend, see Fig. 2.24*b*.

holding block are used to keep both halves of the die aligned for each shot.

Surface pins *AA* slide through holes in the ejector die and protrude beyond the surface of the ejector-die holding block. One end of the pins strikes the surface of the cover-die holding block when the die

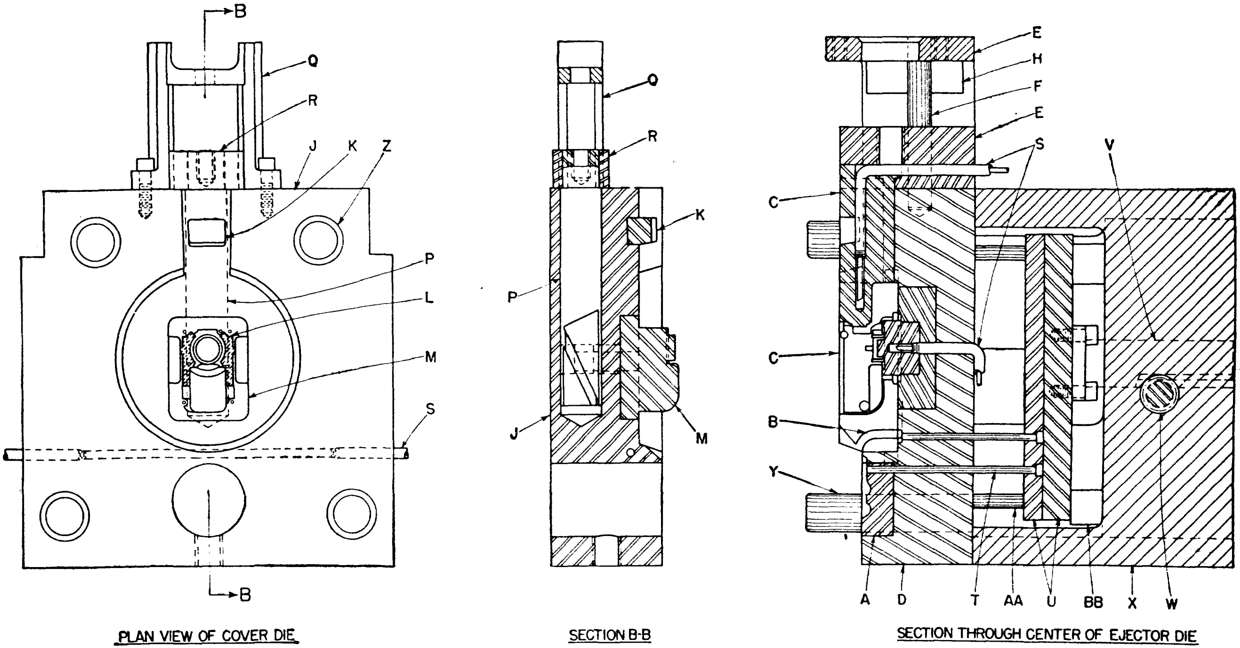
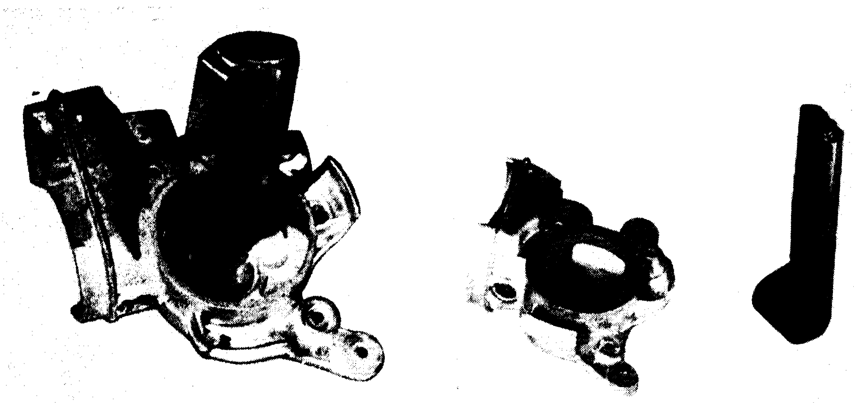


FIG. 2.24*b*. Plan view of cover die and section view of the cover and ejector die. See text for operating details. Parts of the die are as follows: *A*, sprue plug; *B*, gate runner; *C*, slides; *D*, ejector-die block; *E*, side backing plates; *F*, guide pins; *G*, hydraulic pull frames; *H*, stops; *I*, ring lock; *J*, cover-die block; *K*, internal lock; *L*, cast-in pole shoe; *M*, impression block; *N*, pole-shoe retainer; *O*, retainer block; *P*, cam; *Q*, hydraulic pull frame; *R*, cam stop; *S*, water lines; *T*, ejector pins; *U*, ejector plates; *V*, racks; *W*, pinion; *X*, die base; *Y*, dowels; *Z*, bushings; *AA*, surface pins; *BB*, ejector-plate stops.

closes. The other end is fastened in the ejector plate in the same way as the ejector pins. If the rack and pinion should not completely withdraw the ejector pins, resulting in the ejector plate moving firmly against the ejector-plate stops *BB*, the surface pins force the plate solidly against them. The die then is ready to make another casting.

Loose Die Pieces. In some applications loose die pieces are preferred, rather than cores. This may be the case when a complex part containing undercuts is to be produced only in small quantities, so that an



a *b*

FIG. 2.25. How loose die pieces are used. In *a* the loose piece is still in the casting after it has been ejected; in *b*, the loose piece is removed to show the undercut that has been formed.

expensive die having intricate cores and core-actuating mechanisms is unjustified. More often, loose pieces are used when coring by either fixed or movable cores is impractical in so far as die construction and operation is concerned.

Loose pieces may be defined as die members that are ejected along with the casting. They then are removed from the casting (Fig. 2.25) either by hand or by means of a fixture and returned to the die. A number of sets of the loose pieces are usually available so that while one set is being removed from a casting another set is being used in casting.

Loose pieces must be fabricated in such a way that they fit accurately and closely in order to minimize the formation of seams on the casting. They must be designed to permit speedy positioning in the die and ease of withdrawal from the casting and return of them to the die. They also must be made of the proper steel and heat-treated to required hardness to resist wear and battering in use.

A drawing of a die having five loose pieces for producing a fan for a hand vacuum cleaner is shown in Fig. 2.26. Toggle-actuated slides at the sides of the die block are moved in toward the die cavity before the

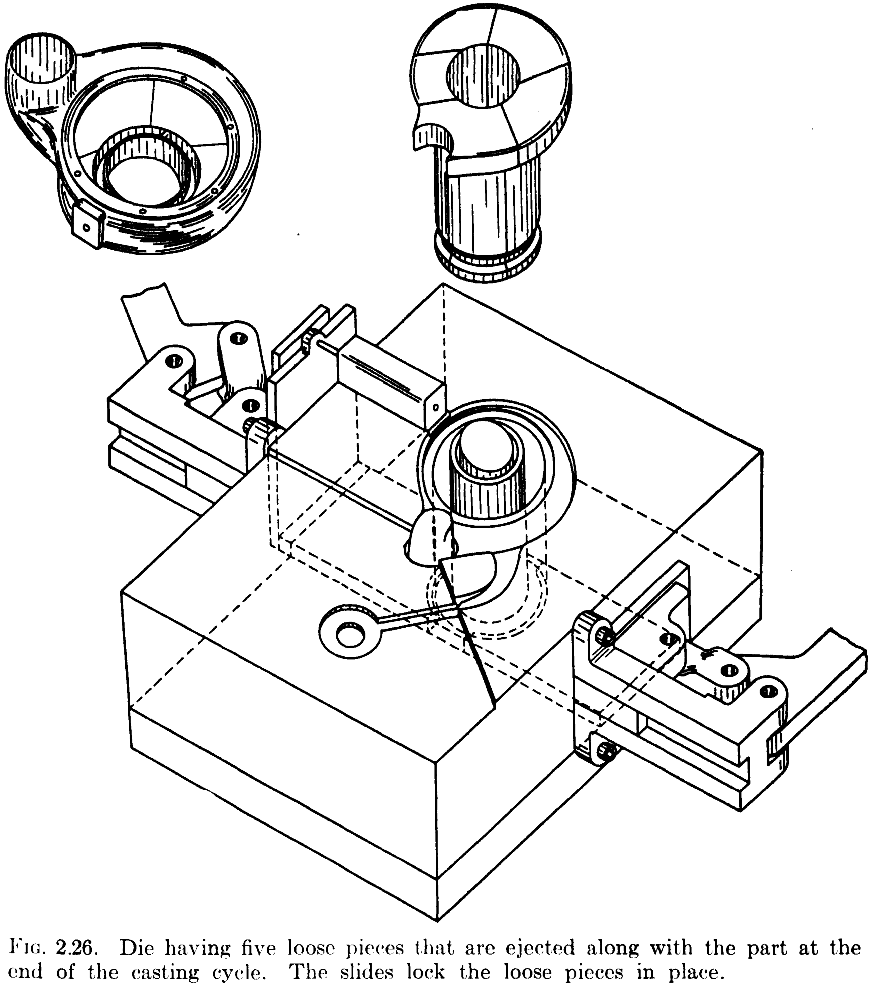


FIG. 2.26. Die having five loose pieces that are ejected along with the part at the end of the casting cycle. The slides lock the loose pieces in place.

shot is made. These plates surround the loose pieces at the undercut collar and hold them in position. After the shot is made, the slides are retracted and the casting and loose pieces are ejected as a unit.

Other references to loose pieces, including an illustration of one method of casting a typical part, are made in Chap. 4, Design of Die Castings.

Gating. Among the factors that govern how a die is to be gated, perhaps the most important is the type of casting machine with which it is

to be used—the submerged-plunger type or the cold-chamber type. Unfortunately, no standards can be set up for the type, location, and design of a gate since die castings differ radically from one another in size and shape, and each must be considered individually.

Many attempts have been made to develop a formula for indicating the type of gating (and its relationship to runners, feeders, vents, and overflows) which will yield the best surface condition and maximum internal soundness in a die casting. Such a formula may possibly be applied to simple geometric shapes, such as a rectangle or circle without holes, bosses, or lugs, but for the regular run of die-cast parts the matter of gating and venting is still empirical, and the die caster must rely upon experience, past performance, and cut-and-try methods.

It would be quite impossible to discuss all phases of gating and venting; however, there are a few important matters in connection with gating practice that can be considered in somewhat general terms.

The extent of the gate opening is dependent upon the wall section of the casting. Obviously, the gate should not be heavier than the maximum wall-section thickness, and surface finish and internal soundness may govern its size to some extent.

In a new die it has been the practice to lay in a gate of the smallest dimension thought practicable, or to have less gate opening than may be subsequently found desirable. If operation of the die indicates that the gate should be larger, additional stock can readily be removed from the die surface. Should it be found, however, that the original gate dimensions are too large and it is necessary to reduce or narrow the opening, the only recourse is to weld up the whole gate opening and start over again.

A so-called "heavy" gate opening is usually over 0.050 in., while a "thin" gate is classed as being about 0.025 in. thick. Some very large castings may have an opening of 0.090 in. or more, while very thin-walled castings may have gates smaller than the recommended minimum.

The greatest advantage of a heavy gate opening is that it permits the metal to flow into the casting as a stream rather than as a spray. Heavy gates, coupled with a relatively slow shot speed and regulated die temperatures, promote maximum soundness in a casting. One disadvantage of a heavy gate, however, is that the gate cannot be removed so readily from the casting and invariably must be trimmed off the casting rather than broken off by hand.

Thin gates, on the other hand, especially for small sectioned castings, are useful for producing good surface finish when internal soundness is of secondary importance. One disadvantage associated with the use of

a thin gate is that "soldering" or welding of the cast metal to the die surface is more apt to occur. This causes a build-up on die surfaces at the gate which adversely affects the finishing of the castings. Such soldered surfaces must be removed from the die by abrasives or by chemical treatment. Such treatment may be only temporary, however, and if the condition is not remedied by a change in the gate, the soldering will reform.

Various types of gates, runners, and feeders that are typical of those used on cold-chamber and submerged-plunger machines are shown in Fig. 2.27. The disposition, area, and design of gate runners, which are channels leading from the gate and feeding the impressions, are important; but again, they are based primarily upon experience. The

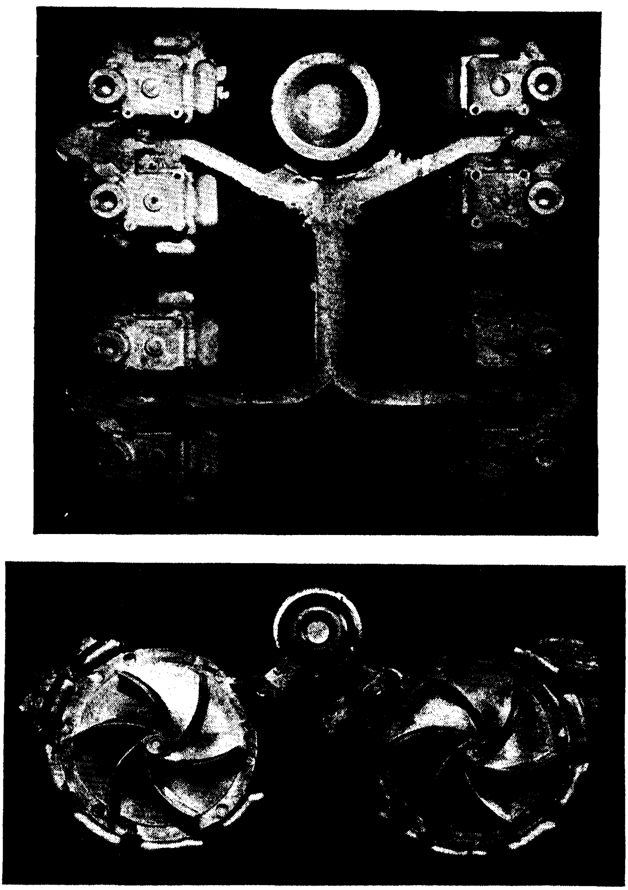


FIG. 2.27. Some of the more common gate designs for multiple-impression dies.

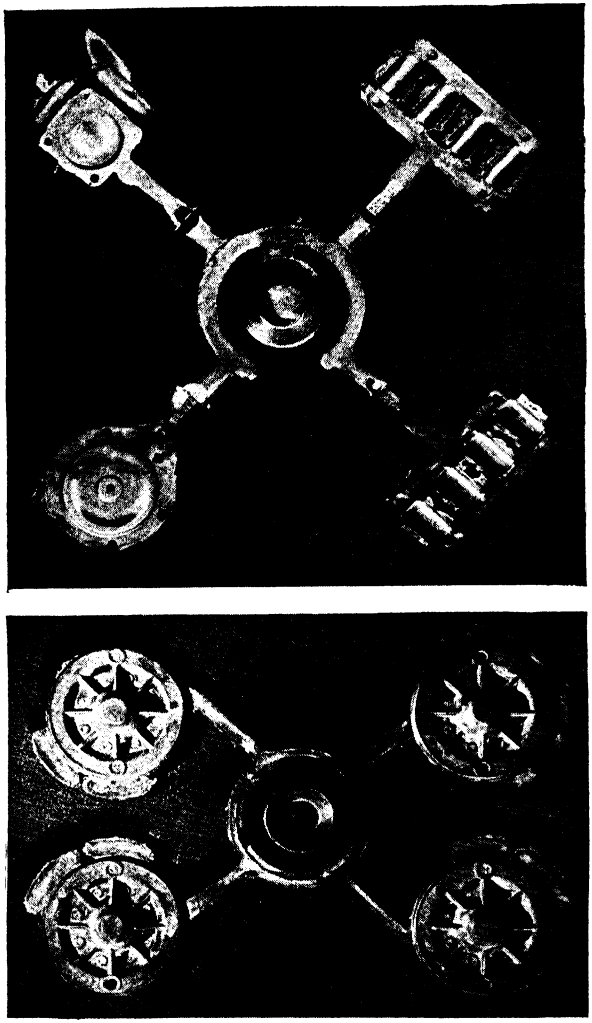


FIG. 2.27. (*Continued.*)

various illustrations of die designs and photographs of gates of castings throughout this chapter will clearly point out the various types of runners, as well as gating, overflows, and venting.

Metal feeders are small openings at the edge of the impression. The gate runner conveys the metal to the feeder and is steeply tapered at the end that adjoins the feeder in order to throw the metal at the proper angle through the feeder opening and dispense it throughout the impression. The four feeders shown in Fig. 2.28 illustrate the more standard

or perhaps the more frequently used types. A determining factor in the design of a feeder is the location of the parting line. The parting line may be made at such a point that a deep cavity in one half of the die and a shallow cavity in the other half is the result. This situation makes

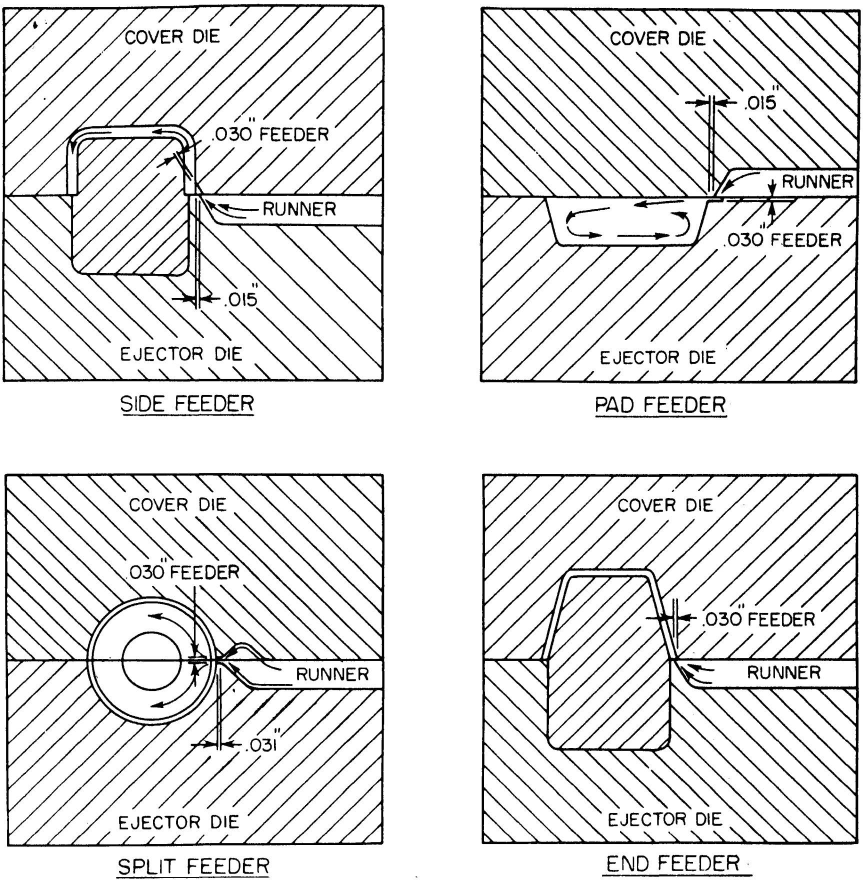


FIG. 2.28. Different types of die feeders. These indicate merely a few possibilities; feeders must be individually tailored to each die.

it necessary for the metal to flow into the impression at a steeper angle in order to fill out the deep cavity.

The utility of a feeder depends largely upon the experience of the designer and his ability to design a "tailor-made" feeder to function best in a particular die. It would be impossible to illustrate all the varied designs for feeders, since their design depends largely upon the shape of the casting. No standard, therefore, can be made.

A single-impression aluminum die having ring gates and a ring lifter is shown in Fig. 2.29. Aluminum alloy enters the die through the sprue plug A; it travels along the gate runner B and into the impression held in a die holding block C. Two cores D protrude into the impression and form the cored holes in the casting. These cores are connected to the

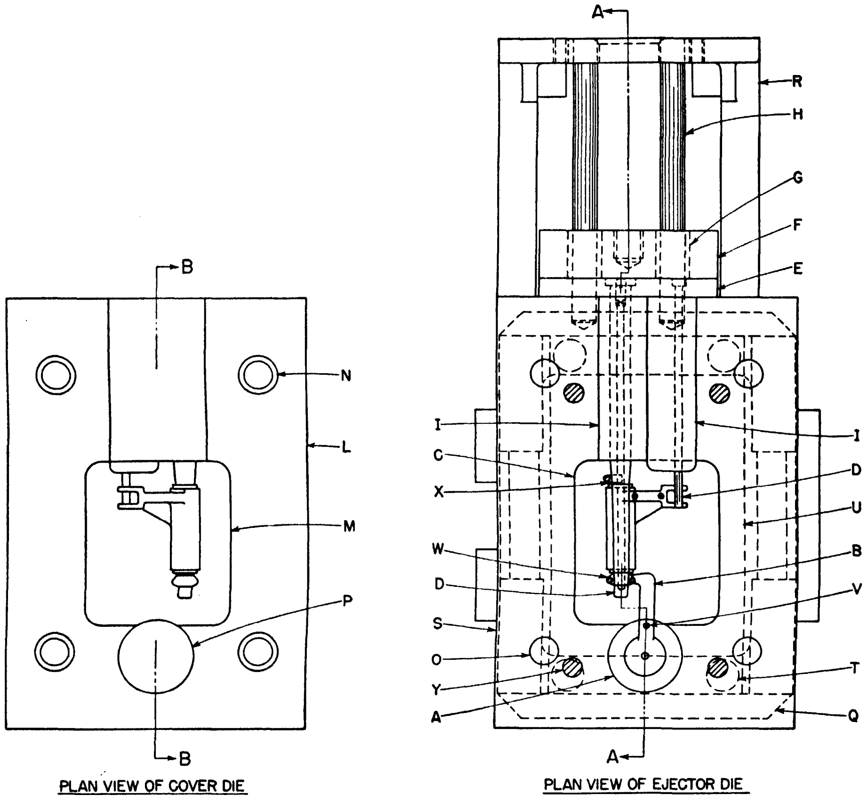


FIG. 2.29a. Plan views of single-impression die having ring gates and a ring lifter, hydraulic core pulls (cylinders not shown), and a hydraulic die base.

core plate E and are backed up by the core backing plate F. This backing plate is equipped with bushings G and slides back and forth on guide pins H. Core bearing blocks I are used to hold the long slender cores in place while the casting is made. Cooling water enters through water-inlet tube J and leaves through water-outlet tube K to cool the larger core.

The cover-die holding block L holds the cover impression block M in place. Bushings N are mounted in the cover holding block in position to fit over the dowel pin O in the ejector half. The hole P in the cover

die is made to fit the cold shot sleeve through which the metal is forced under pressure to the sprue plug.

Die base Q is a cast-iron casting which is bolted fast to the movable plate on the casting machine and which is used to hold the ejector-die

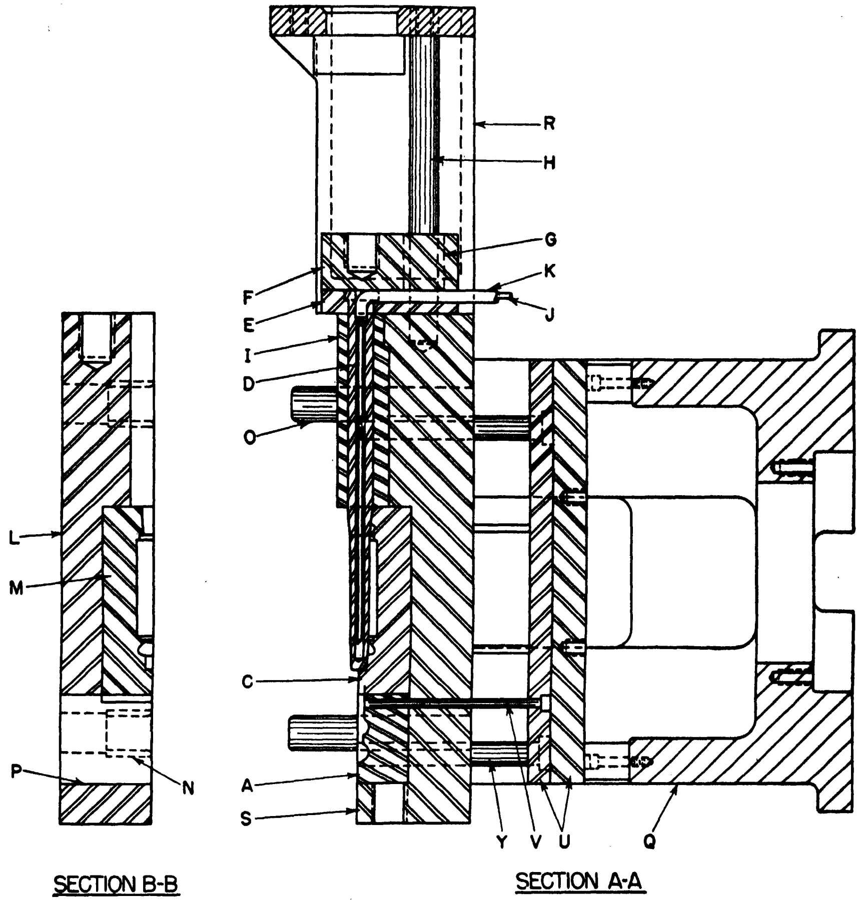


FIG. 2.29*b*. Section views of single-impression die.

block complete with the hydraulic core-pull bracket R, which is fastened to the ejector holding block S. Stops T limit the length of travel to the ejector plates U so that the ejector pins return to the same position each time. The ejector plate is actuated by a hydraulic cylinder (not shown) that is mounted within the die base. Ring gate W and ring lifter X are projections at the side of the cored hole and are used as metal conveyors and pads against which the ejector pins push when ejecting the casting. These gates are later removed from the casting by a trimming operation.

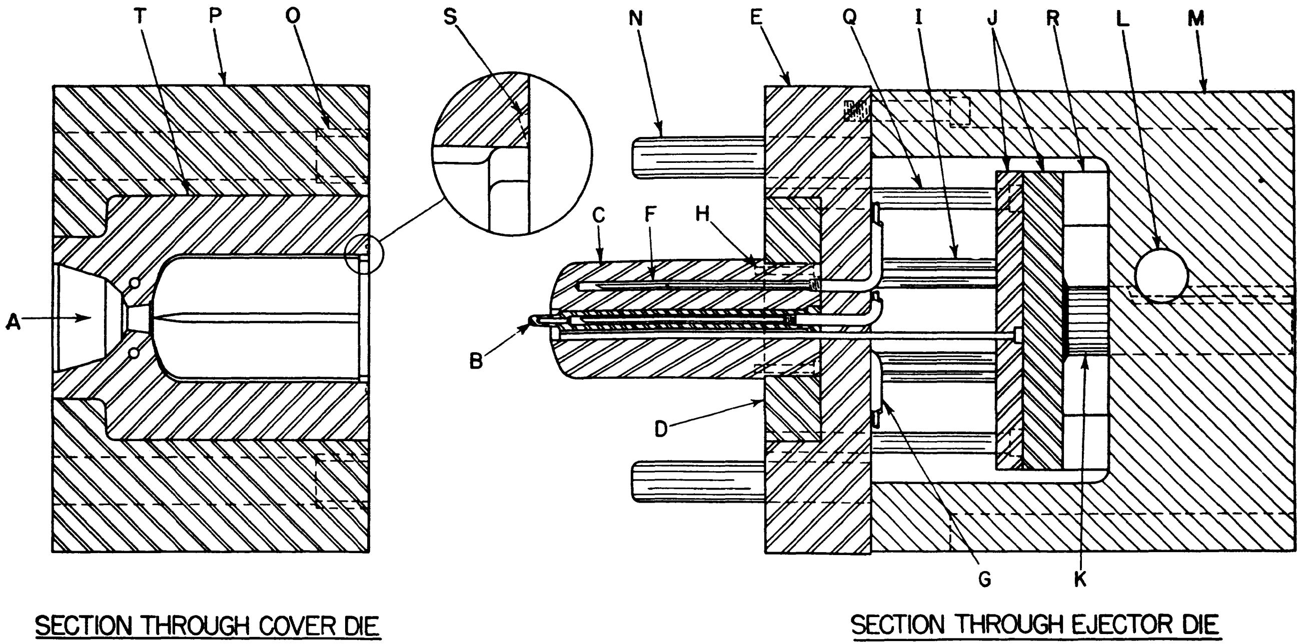
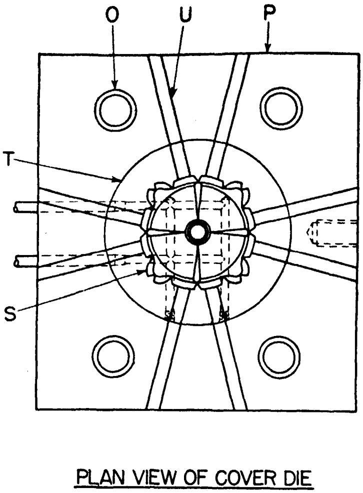


FIG. 2.30. Die for producing a large cylindrical part. An unusual method of gating plus safety edges that allow the flash to break clear are features of this die. Parts of the die are as follows: *A*, sprue nozzle seat; *B*, sprue post; *C*, center core; *D*, impression block; *E*, ejector-die holding block; *F*, water-inlet tube; *G*, water-outlet pipe; *H*, cores; *I*, ejector pins; *J*, ejector plates; *K*, racks; *L*, pinion hole; *M*, die base; *N*, dowels; *O*, guide bushings; *P*, cover-die holding block; *Q*, surface pins; *R*, ejector-plate stops; *S*, safety edge; *T*, impression block; and *U*, air vents.



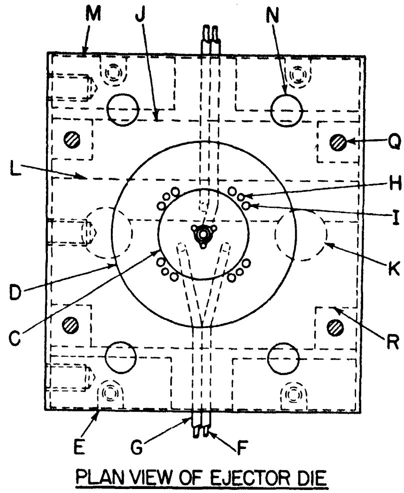


FIG. 2.30. (*Continued.*)

Surface pins *Y* slide through holes in the ejector die, as do the ejector pins, and are connected to the ejector plate in the same manner as the ejector pins. The purpose of these pins is to guide the ejector plate and keep it parallel during its movement to prevent jamming. Since the hydraulic cylinder moves the plate back as well as forward, the surface pins ensure that when the die is closed the plate is solidly against all stops and all ejector pins are in their proper positions for making the casting.

The die shown in Fig. 2.30 also employs a somewhat unusual method of gating because the design of the casting makes an internal sprue post necessary. Zinc metal is forced through a nozzle (not shown) that fits snugly in the sprue nozzle seat *A*. Metal strikes the internal sprue post *B* in the end of the large center core *C* and is diffused throughout the die cavity. The large core is mounted in the ejector impression block *D*, which in turn is mounted in the ejector holding block *E*.

Three inlet *F* and outlet *G* tubes serve the large core with water to maintain it at the proper casting temperature. Another tube serves the internal sprue post with water to keep it at the right temperature.

Four smaller cores *H* form holes in the bottom wall of the casting. These cores are stationary and are seated in the impression block. The ejector pins *I* slide through holes in the ejector die and are fastened at one end to the ejector plate *J*. The other ends of the pins contact the casting and push it from the impression. Two racks *K* welded fast to the bottom of the ejector plate and a pinion *L* set in a hole drilled in the die base *M* actuate the ejector mechanism.

Four dowel pins N set in the ejector-die holding block and four bushings O in the cover-die holding block P are used to keep both halves of the die in alignment.

Surface pins Q slide through holes in the ejector die and protrude beyond the surface of the ejector-die holding block. One end of the pins strikes the surface of the cover-die holding block when the die closes. The other end is fastened in the ejector plate in the same way as the ejector pins. If the rack and pinion should not completely withdraw the ejector pins, resulting in the ejector plate moving firmly against the ejector-plate stops R, the surface pins force the plate solidly against them. The die then is ready for the injection of metal.

Safety edges S, shown in the enlarged inset, are cut into the impression block T around the edge of the cavity in the cover die. Their purpose is to make the flash, which always appears at the parting line, break clean when the casting is trimmed, thereby eliminating the need for a more costly trimming die to trim these edges closely and making necessary only a rough or loosely fitting die plate in the trimming die. Were it not for these edges, the flash would leave a small burr bent back along the wall of the casting, making it difficult to trim cleanly.

Safety edges in a die also serve to keep the edge of the impression from peening over, as would happen in some cases due to the contact between both halves of the die when closing. A condition of this kind causes the casting to gall the core as it is being withdrawn from the cover die.

Air vents U, which are about 0.005 or 0.006 in. deep, allow air trapped in the cover die to escape when the metal displaces it.

Venting. All dies must be properly vented with means for the escape of air in the die impression prior to the entry of the metal. If suitable escape channels are not provided, the air may be trapped in the casting, giving rise not only to porous castings but also to blistering of the casting surface.

Venting is usually accomplished by the use of small channels of about 0.005- to 0.006-in. thickness on the parting line of the die and at locations most likely to cause entrapment of air. In addition to such channels, it is common practice to place draw pockets or overflows, which essentially are small cavities properly disposed around a casting impression, to provide additional escape areas.

Water Cooling. Even though die-casting machines are operated at a predetermined number of cycles in order to control die temperature, certain sections may retain more heat than others. These sections—heavy walls, and gating points where the force and speed with which the metal is injected raise the temperature to a high level—must be maintained at

the correct temperature by water cooling. Slides, cores, and other movable parts of the die also may be water-cooled to avoid seizure and ensure ease of actuation.

The water is carried through these sections by cooling lines or channels that are drilled in the die block (Fig. 2.31; also see illustrations of previous dies). In some cases, the water lines are drilled all the way through the blocks; in others, as shown in the cover-die insert, they are drilled in such a manner that the water flows through one nipple or short pipe, circulates around the areas to be cooled, and flows out through the other pipe. In any event, the water-line openings must be so arranged that there is no leakage, particularly at parting-line surfaces of the die, since any water coming into contact with the molten alloy entering the die may cause an eruption or minor explosion. The clearance holes are drilled through the main die surface, and the nipples screwed into the round inserted center block.

Single-return water lines also are sometimes used, as in the cover die. These differ from through water lines in that they contain an internal copper tube through which water enters the die and around which it returns to the source. The copper tube is usually fastened in the inlet of a Y fitting and located in the hole to a depth of approximately 1/4 in. from the end. Through water lines should be used whenever possible because they provide the die with a greater amount of coolant. The application of single lines usually is confined to cores, slides, or thin sections in which there is insufficient space for a through line.

In laying out dies and die parts, good design practice dictates that the water lines should be no closer than approximately 3/4 in. from any point of a die impression or die part. This is necessary to prevent the thermal shock on the steel from resulting in breakage or cleavage cracking. Of course, in some small sections and cores this minimum may necessarily have to be less, but it is well to keep in mind the need for maintaining as much stock as possible.

A little water should always be coursing through the water lines in a die during the start of production or during the interval when the die is being brought to operating temperature. Otherwise, if cold water is suddenly run through a hot die, the die may split.

Also, it is absolutely essential that full consideration be given to the hardness of the water being used. The use of water having an appreciable hardness, either temporary or permanent, may result in the deposition of scale in the lines. Such scale, no matter how thin, is a good thermal insulator and tends to nullify any cooling that the water might otherwise effect. The problem can be solved in either of two ways: by using water having a very low hardness and periodically cleaning out

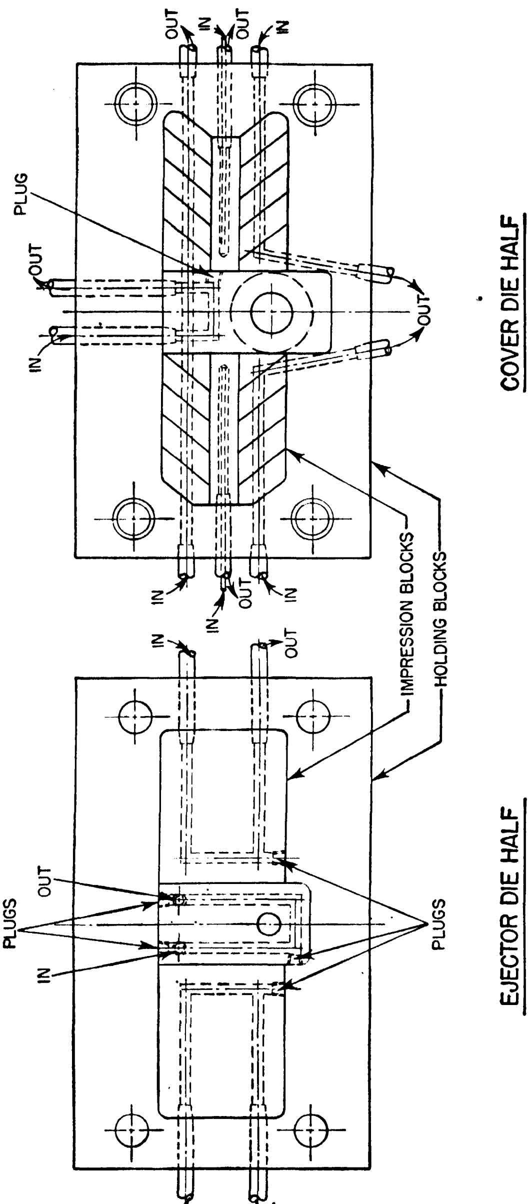


FIG. 2.31. Multiple-impression casting die showing the water-cooling lines in the cover- and ejector-die halves.

the lines with a dilute acid that will dissolve the scale; or by installing water-softening equipment that will prevent the formation of scale.

CLASSIFICATION OF DIES

Die-casting dies can be roughly classified into five types: single impression, multiple impression, combination dies, unit dies, and adjustable dies for different lengths and widths of castings.

Single-impression Dies. A single-impression die is probably the most universal type used by all die-casting plants. Since it contains only one cavity, which is machined or hobbed in the mating halves, it is basically the least complex and easiest to build. For small, simple castings, it is inexpensive and therefore often is used when production requirements are low; for medium- or large-sized parts, it may be the only practical unit that can be used because of the size limitation of the machine. For all practical purposes, it may be considered as the standard die-casting die, all the others being modifications of it to achieve faster and more economical production.

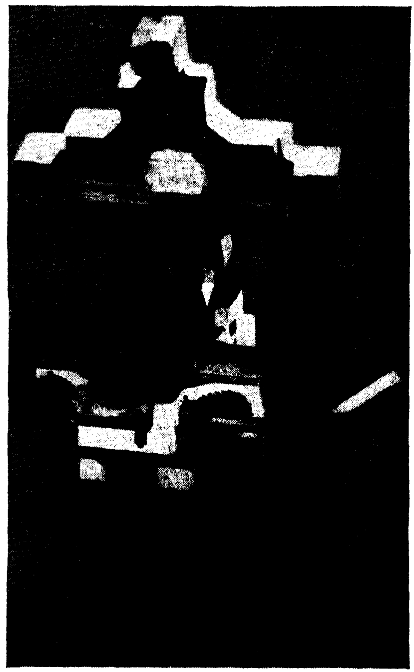


FIG. 2.32*a*. Single-cavity die for casting an aluminum part having thin walls. Features include slides, left and right, that form two sides of the casting, and a ring ejector system to minimize casting distortion.

One single-impression die for casting an aluminum boxlike part having thin walls and no built-in bosses or other heavy sections that can be used as ejection points is shown in Fig. 2.32. The cavity in the ejector die is formed partly by the use of two slides *Y* that enclose two of the walls of the casting. These slides are drawn away from the casting following the shot and greatly simplify its removal from the die cavity. A rectangular ring *H*, the inner edge of which forms the edge of the four walls of the casting, is actuated by the ejector plate *G* and its connecting rods. When the

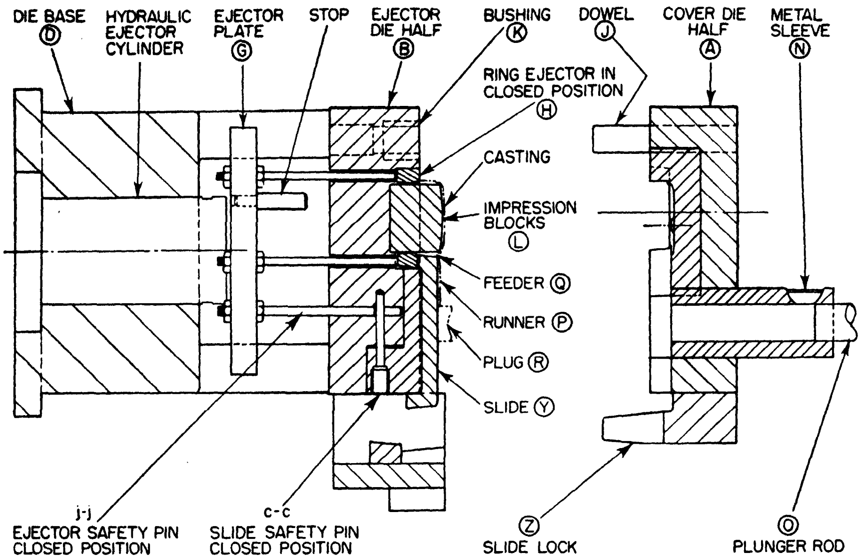


FIG. 2.32*b*. Section of ejector- and cover-die halves.

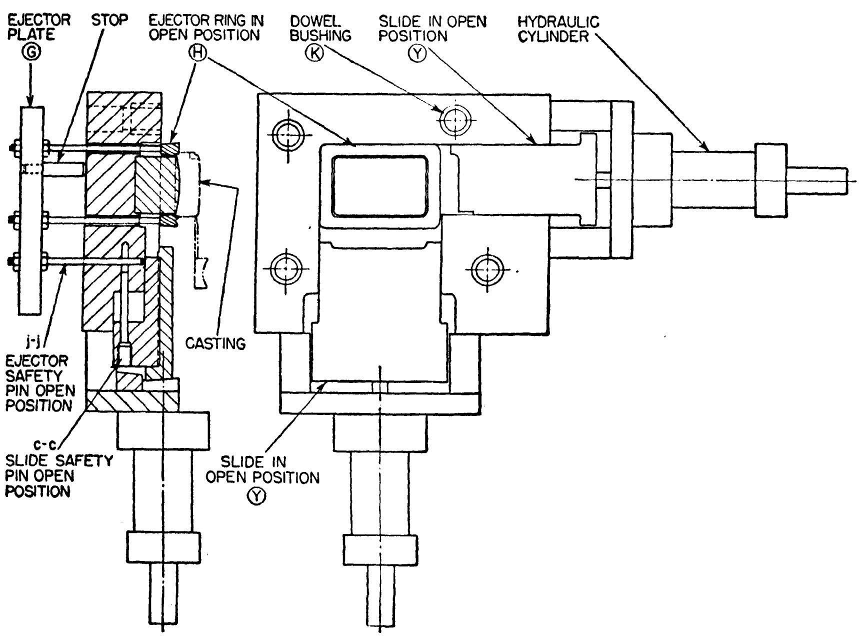


FIG. 2.32*c*. Section and plan of the ejector-die half.

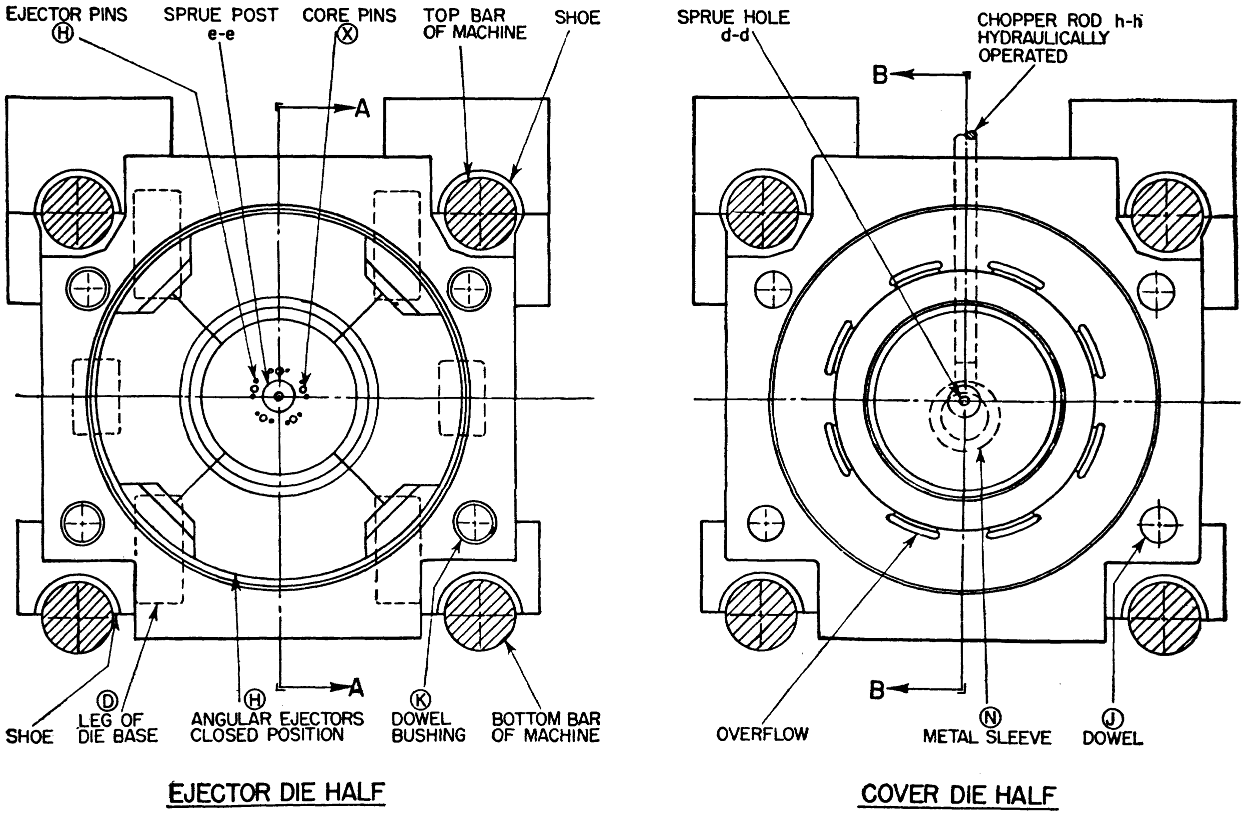


FIG. 2.33*a*. Plan view of large die for casting a magnesium automobile wheel having a deep undercut around the circumference.

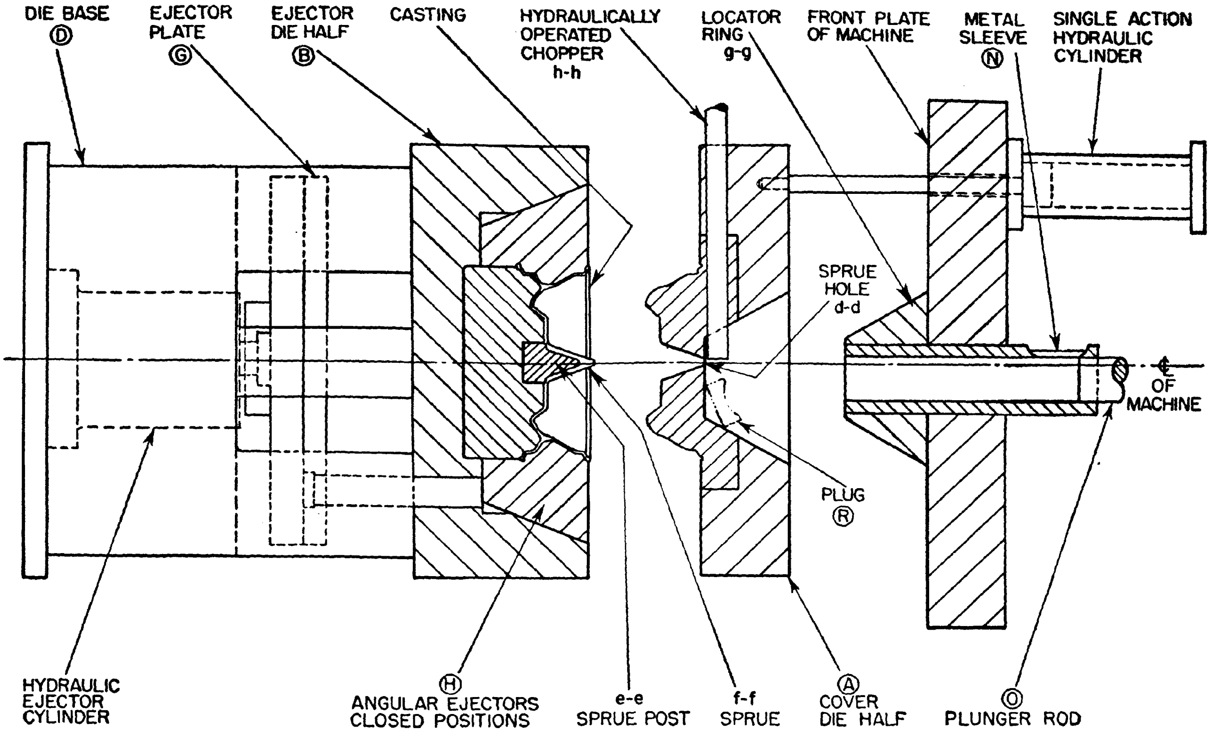


FIG. 2.33*b*. Section of the ejector- and cover-die halves showing the casting in the cavity.

casting is ejected, this ring travels away from the face of the ejector die, but is at all times parallel to it, and removes the casting from the core.

A double safety-pin feature is incorporated in the slide mechanism to prevent damage to both the casting and the slide by blocking an ejection movement until the slides have been opened. Once open, the ejecting

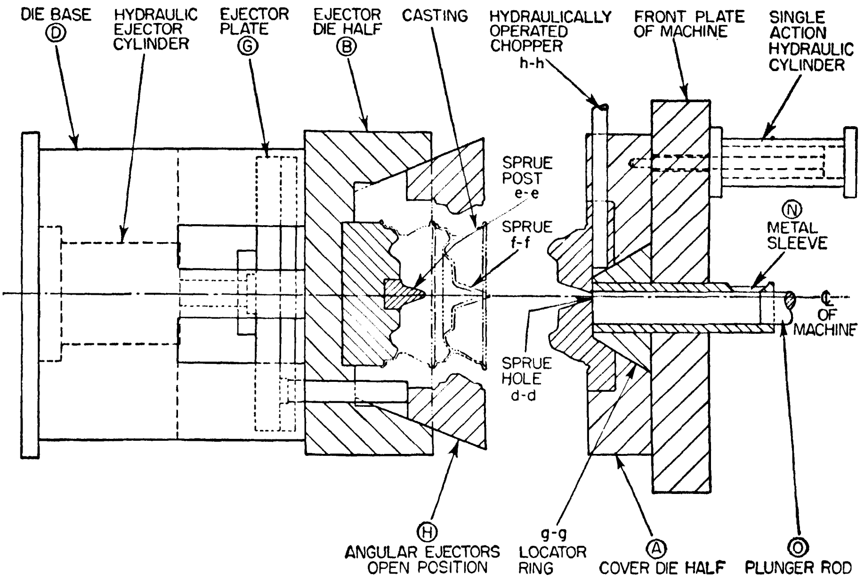


FIG. 2.33*c*. Section of the ejector- and cover-die halves with the die in the open position and the casting (shown dotted) ejected.

mechanism is free to operate as described, and in this position the ejector safety pin *j-j* has blocked the slide safety pin, which prevents the slides from closing onto the ejector ring *H*. When the die is shut, two slide locks *Z* keep the slides *Y* in the proper casting position.

A large single-cavity die for casting a magnesium automobile wheel, the tire wheel necessitating a deep undercut on the outer circumference of the casting, is shown in Fig. 2.33. Several features not employed in the preceding die appear in this one. The metal is ladled into the metal sleeve *N* and is then forced by the plunger rod *O* through the sprue hole *d-d* located near the top of the inside diameter of the sleeve. This hole is placed to prevent the metal from running into the die cavity before the shot is made. The sprue post *e-e* is a tapered core and deflects the metal into the die cavity and also reduces the size and strength of the sprue *f-f*, which is afterwards removed from the casting.

After a shot has been made, the ejector- and cover-die halves move away from the locator ring *g-g* fixed to the front plate of the machine. The cover die travels only as far as the stroke of the single-action hydraulic cylinder set on the front plate will permit. The hydraulically operated chopper *h-h* has been timed to cut off the plug *R* at this point in the cycle, and the ejector-die half *B* continues to move to the limit fixed by the opening of the machine. A hydraulic cylinder actuates the ejector plate *G*, and the angular ejectors *H* fastened to it move forward from the face of the ejector die and outward from the center line of the machine. This frees the casting and permits it to be removed from the die, as shown in Fig. 2.33*c*.

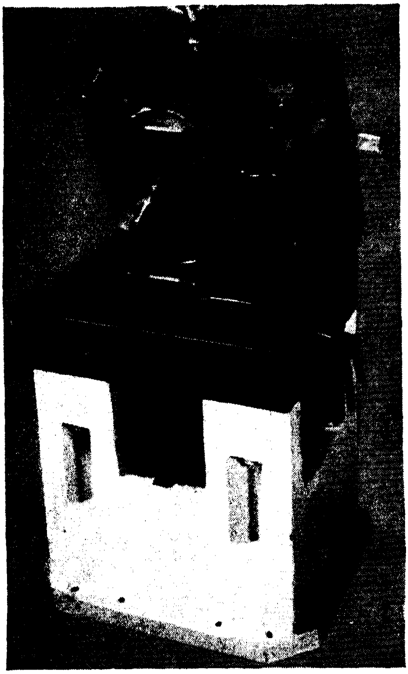


FIG. 2.34*a*. Simple combination die having two dissimilar impressions for casting small aluminum parts. Dies such as these are used quite frequently when production requirements of the two parts are similar.

Before the next shot is made, the angular ejectors are drawn back and the machine starts to close. The ejector die contacts the cover die again in this closing movement and carries it back onto the locator ring. In the meantime, the plunger rod in the metal sleeve has moved back to casting position and the machine is ready for the next shot.

Both of the dies shown in Figs. 2.32 and 2.33 are rather complex in that special features are incorporated in them to facilitate the casting and ejection of the part. Many single-impression dies are much simpler in construction, and so, as a matter of fact, are many of the combination dies.

Combination Dies. Combination dies and multiple dies both have the same purpose: to permit the casting of two or more parts simultaneously. Thus, both contain two or more die cavities. The difference between them is that the multiple die is used for castings that are similar (*i.e.*, for the casting of several parts of the same shape), while the combination die is used for castings that are different (*i.e.*, for the casting of two or more parts of unlike shape). Also, the number of cavities in the com-

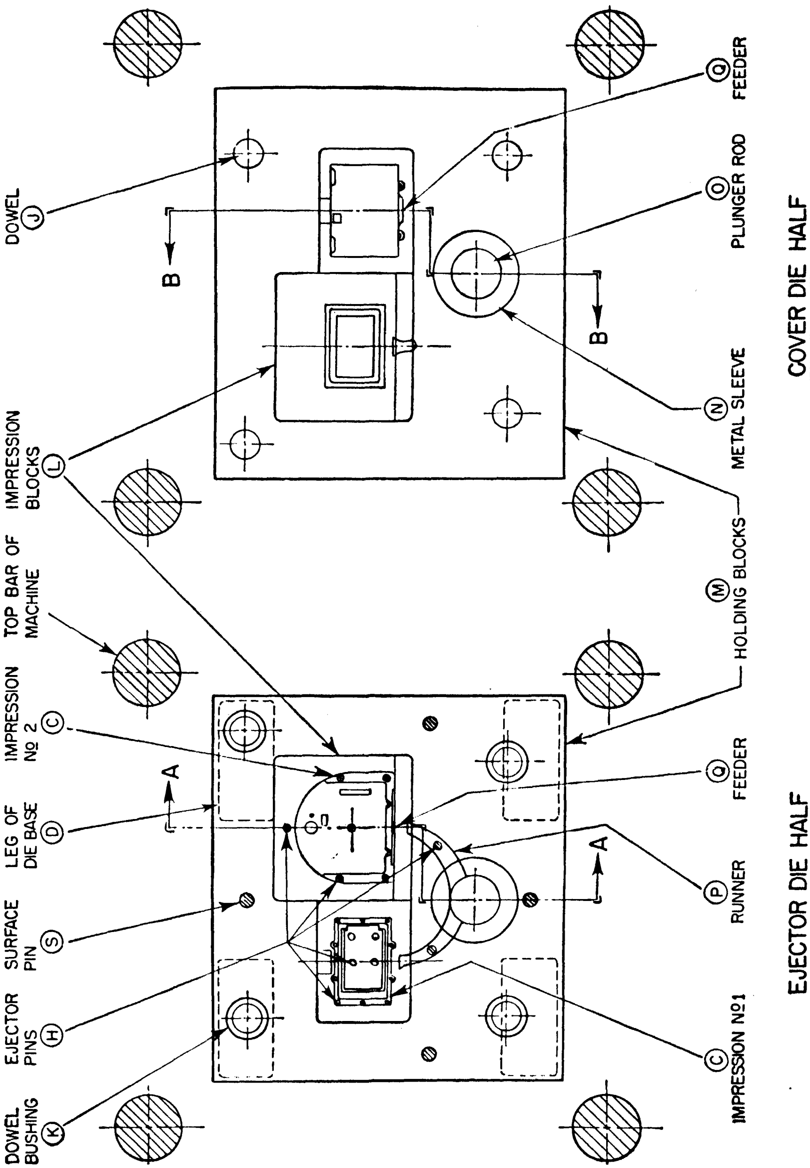


FIG. 2.34*b*. Plan view of the ejector- and cover-die halves.

bination die often is limited, while a greater number usually are employed in the multiple die.

Combination dies usually are used for different parts of the same assembly whose production requirements—either large or small—always are similar. Multiple dies, on the other hand, are confined almost entirely to small parts that must be produced in quantity, such as certain business-machine castings.

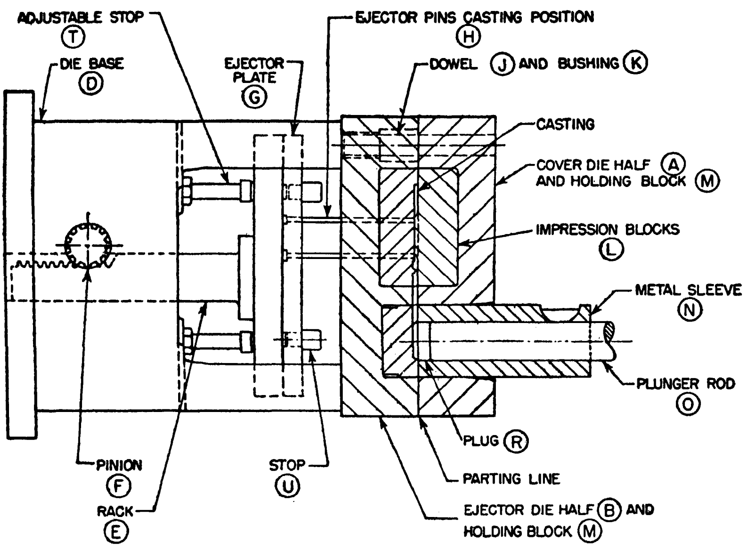


FIG. 2.34c. Sections of the cover- and ejector-die halves with the die in the closed position.

The primary purpose of a combination die is, of course, to reduce cost —to use one die block instead of two, and to produce two or more parts per casting cycle instead of one. The precaution that must be observed is to balance the die thermally.

The parts to be die-cast may vary considerably in shape and size. For this reason it is sometimes quite difficult to obtain a thermal balance in the die; but when the die is designed the impressions should be disposed with the view of obtaining the maximum uniformity of heat input.

A simple combination die for casting platelike aluminum parts is pictured in Fig. 2.34*a*, and assembly drawings are shown in the subsequent illustrations. The ejector-die half is mounted on the movable rear platen of the casting machine and has a die base or ejector box *D*, which contains whatever mechanism is needed to pull cores and eject castings from the die. This may be done with the aid of a hydraulic cylinder or simply

a rack E and pinion F to actuate the ejector plate G and the ejector pins H, which eject the casting from the die.

In dies of simple construction such as this, the major area of the impressions C may be in either the ejector- or the cover-die half. However, the ejector-die half must be designed with sufficient projection or cores onto which the casting will shrink as it cools and thus come free from the cover die and remain in the ejection die when the machine is open.

The cover-die half is mounted on the front plate of the machine and is stationary. Registry between the two die halves is maintained by the use of dowel pins J and bushings K, generally located as shown. When the machine is closed, the die halves are brought into the casting position (Fig. 2.34*c*) and the metal is ladled into the metal sleeve N by the operator; a hydraulically operated plunger O forces it into the die cavity through a passage known as a runner P and feeder or gate Q, thus filling the die cavity. The feeder is cut in the face of the die deep enough to maintain the casting proper, the runner and plug R (formed by excess metal left in the sleeve after the shot is made) in one piece for ejection and handling before inspection where the casting is broken off and the runner and plug are returned to the foundry for remelting.

In opening, the ejector die travels away from the cover die and carries the casting with it. The casting, runner, and plug are then ejected from the die as shown. Before the machine is closed in preparation for the next shot, the ejector pins H must be drawn back by the ejector mechanism. To ensure proper surface and depth location of the ejector pins on the surface of the castings, pins known as *surface pins*, S (Fig. 2.34*b*), that extend through the face of the ejector die are contacted by the face of the cover die as the machine is closed. This locates and holds the ejector pins H and ejector plate G against the adjustable stop T, and stop U limits forward movement of the ejector plate and pins. This combination compensates for any looseness or play in the rack and pinion of the ejector mechanism.

Another and somewhat larger combination die having two cavities for casting two dissimilar ringlike brass parts is shown in Fig. 2.35. A large core X is necessary to form the inside diameter of the casting and must be amply supported to prevent any back movement when the shot is made. A stop U is placed behind the core rack and mounted on the fixed plate.

In cooling, the casting shrinks onto the core, and since the inside edge of the casting is too light to be used as a surface for the usual method of ejection, a stripper die base is used with this die. The shrinkage of the casting on a core of this size is generally such that the die base D

and its die half B move back with the fixed plate V without opening. When the operator works the rack E and pinion F core mechanism, the back end of the heavy rack is against the stop U on the fixed plate V. This, being mounted on the back plate of the machine, cannot move any farther, the die base D and the fixed plate V, therefore, part from each other, the movement being fixed by the heads on the sliding dowels W, and the die itself strips the casting off the large core. As the outside walls of a casting shrink away from the die cavity, the casting is easily ejected by ejector pins bearing on the bosses and on the plug.

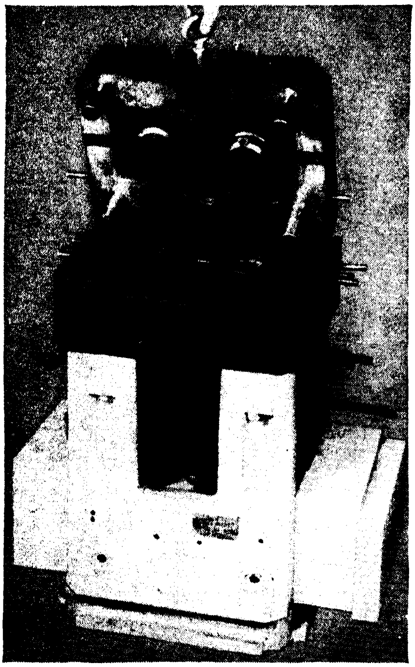


FIG. 2.35*a*. Combination die for casting two dissimilar brass-alloy parts. A stripper-die base is used with this die to eject the part after it cools (and shrinks) on the core.

Multiple-impression Dies. Multiple-impression dies are used where large and rapid production of a part is required. The number of impressions in such a die depends upon the size and shape of the part and the rate of production needed. For some small simple-shaped parts, the number of impressions may run as high as 32 or 48; such dies usually are made for only one type of casting. They may be used, however, to cast two parts that differ from each other only by slight change in orientation, such as the casting of right- and left-handed parts that go into one assembly.

The greater the number of impressions used in a die, the greater the productivity in parts per hour, and consequently the lower the labor cost per piece. On the other hand, the more impressions used, the greater will be the die cost.

The impressions in a multiple die should be arranged symmetrically and uniformly, each impression being equidistant from the other. Impressions may be disposed in a straight line or in circular form (Fig. 2.36). If arranged in a line, the total amount of impressions should be of an even number since it is desirable to have the same number of impressions on each side. In a circular arrangement the impressions may

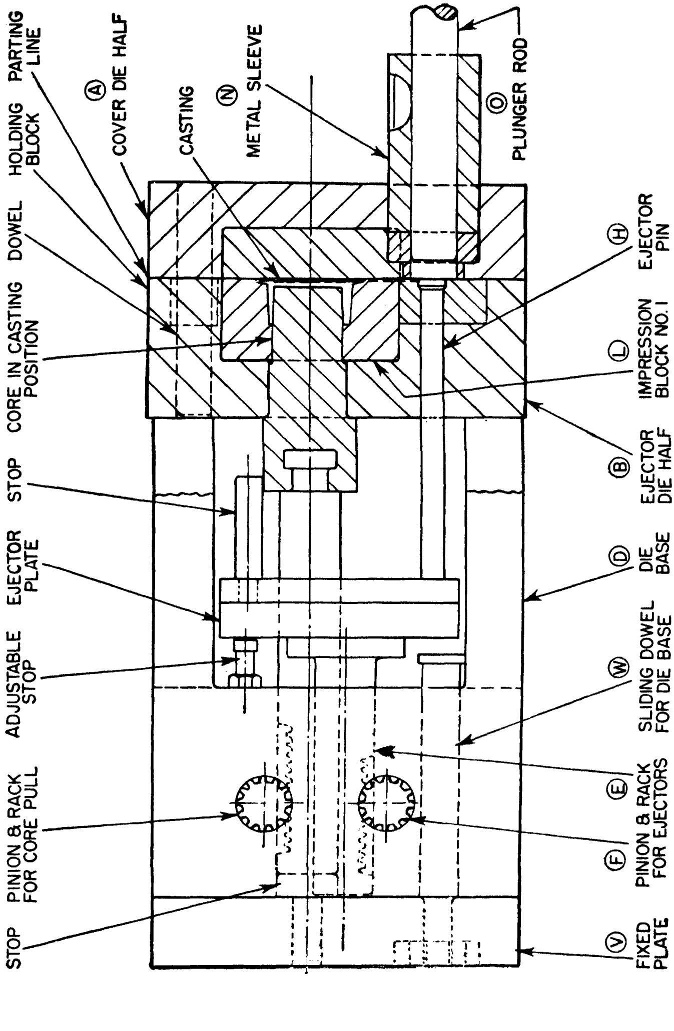


FIG. 2.35b. Section of cover- and ejector-die halves in position for making the shot.

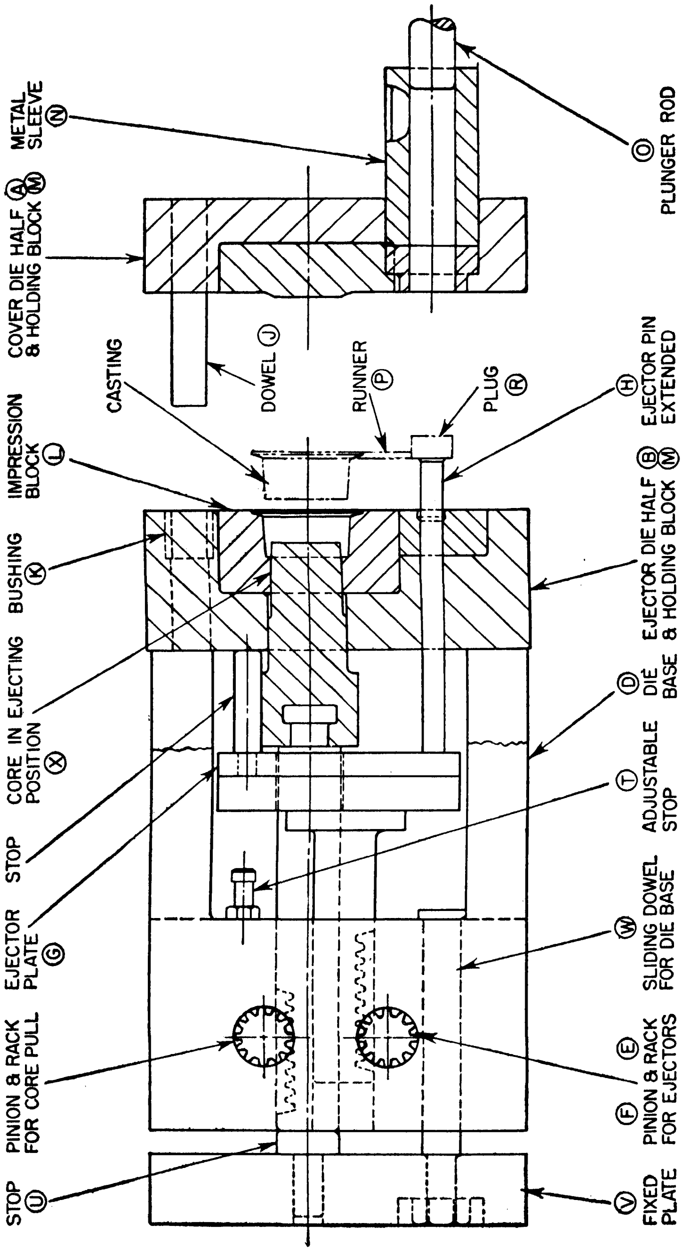


FIG. 2.35c. Section of cover- and ejector-die halves after the die is opened and the casting is ejected.

be either odd or even, as long as they are uniformly balanced. Balancing of the impressions is necessary to obtain uniformity of heat distribution in the die.

Sufficient space should always be provided between the edge of the impressions and the outer edge of the die block. This area, usually termed the *metal seal,* generally should measure not less than 3 in. If

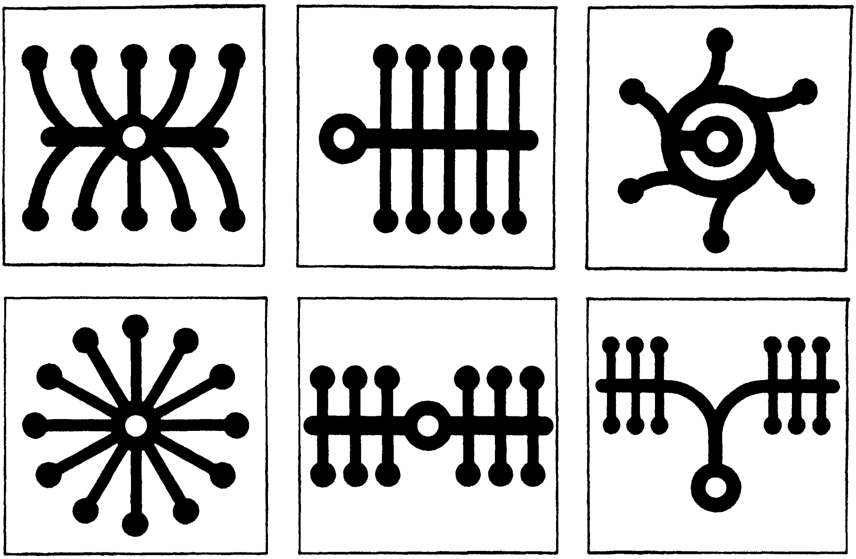


FIG. 2.36. Methods of arranging a multiple-impression die. An even number of impressions should be used if arranged in a straight line to balance the heat distribution in the die. If the impressions are formed on a circle around the center of the die, an odd number can be used.

less than this minimum, the molten metal may shoot out through the parting line, especially if the die blocks "blow" or part slightly under the pressure of the metal entering the die.

A 16-cavity multiple-impression die used to cast duplicate right- and left-hand brass castings of eight each is shown in Fig. 2.37. The principal feature of this otherwise simple die is the use of a series of core pins built into the die to cast a hole in each casting at an angle to the vertical axis of each.

Core plates *a-a* above and below the ejector half of the die hold eight core pins each. Their angular position is maintained by the use of two guide posts *b-b* on which the plates move when the cores *X* are drawn before the ejection of the castings. The fixed position of the core pins for casting is maintained by the use of a wedge lock *Z* on the side of the

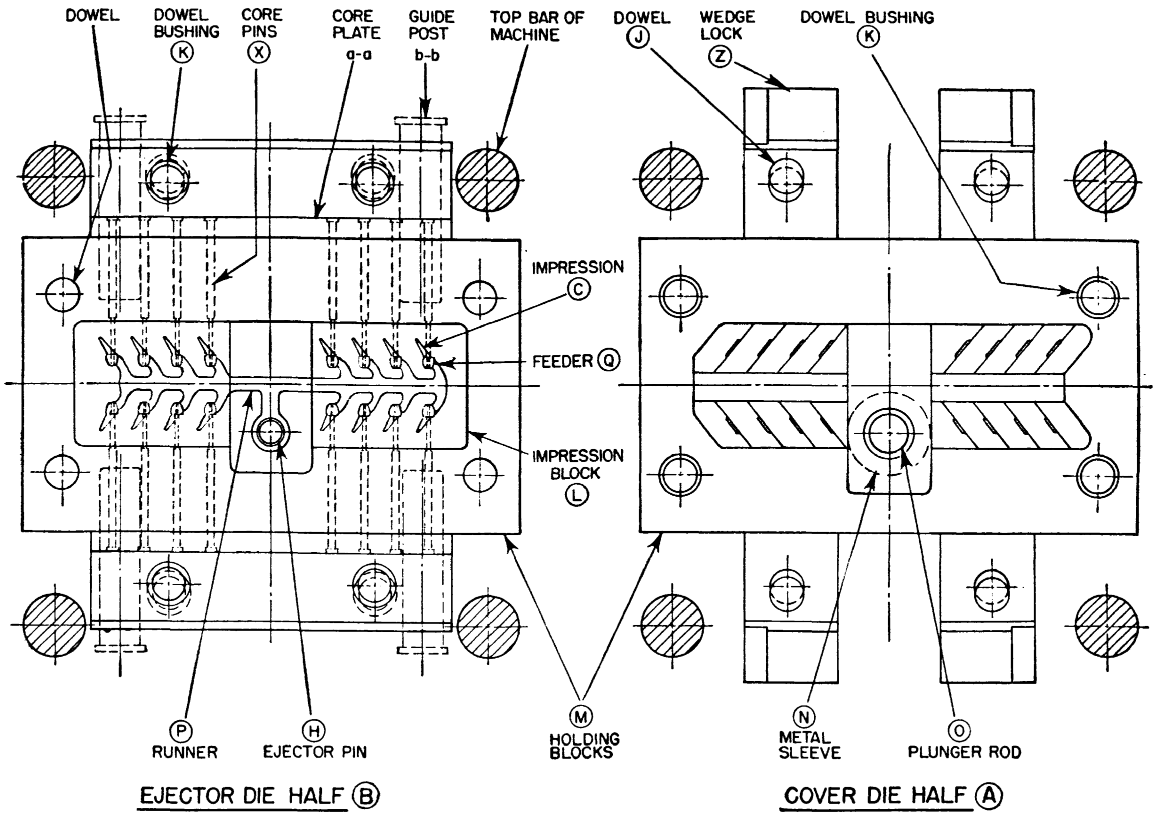


FIG. 2.37*a*. Plan view of 16-cavity multiple die for casting eight right-hand and eight left-hand brass parts. Core pins are used to cast a hole in each casting at an angle to the vertical axis.

cover die that bears on the holding blocks for the cores and locks them in position. When the machine is opened, the angularly set dowels *J* in the cover die move the core mechanism, the limit being held by the heads on the guide posts *b-b* fixed into the ejector die *B*. The core pins are thus drawn out of the castings, and the latter, together with the runners and plug, are ejected from the die.

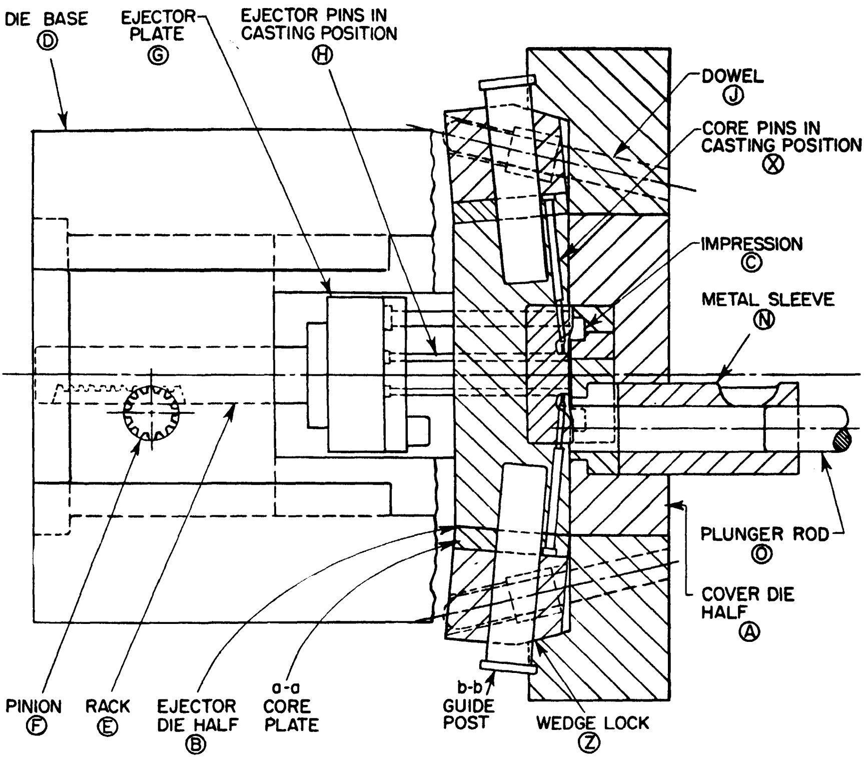


FIG. 2.37*b*. Section of the cover- and ejector-die halves with the die in the casting position.

Attention is directed to the small pieces making up the impression block of the cover-die half. These pieces are used to facilitate the machining of the cavities, which have sharp edges in two sides and could not be milled out if the impression block were of one piece. The small pieces also prevent warping due to the high temperature to which brass dies are subject. Should this occur, the damaged area is easily replaced with a new piece.

Provisions must be made for cooling the impression blocks in the vicinity of the die cavities. Excessive heating greatly lessens the life

of the die. Water is circulated through holes drilled into the holding blocks immediately behind the impression blocks or into them if at all possible (for details see Water Cooling, page 84).

Unit Dies. For the die casting of moderately sized parts, especially when the desired production is relatively low, the use of unit dies is of considerable advantage. The difference between this and a multiple die is that in the latter the impressions are machined or hobbed in the die

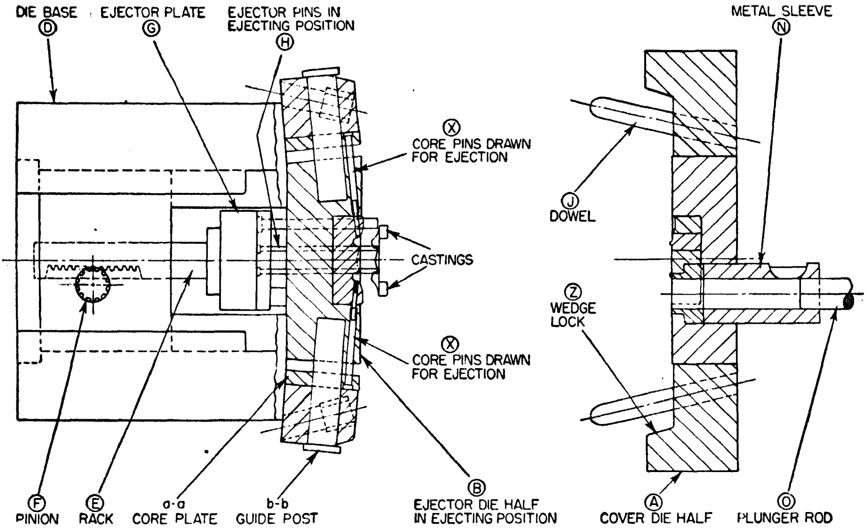


FIG. 2.37c. Section of the cover- and ejector-die halves with the die in the open position and the casting ejected.

halves, while in the unit die the cavities are formed in replaceable die units which then are set in machined location in the die, and to which the charge of metal is simultaneously delivered.

Each of the replaceable units constitutes a separate part. It may or may not differ from the others in respect to the size and shape of the casting impression, but it must have similar outer dimensions so that it can be fitted into the locations in the die. Thus, one unit die may be used to die-cast a number of different parts for a number of different products.

All unit dies have a common supporting mechanism, termed a *master holding die,* that contains the machined locations for the unit blocks. The master holding die is permanently fastened to the die-casting machine, from which the units can be quickly and easily interchanged without interrupting casting operation for more than several minutes at a time. The holding die is gated in order to distribute the casting

alloy to each of the units from a single gate opening, and each unit has an individual ejector mechanism that is coupled with the ejector mechanism of the holding die.

FIG. 2.38. Four-unit die halves, and one set of replaceable rectangular impression blocks used with them. Note that the units for the ejector-die half are equipped with ejector plates.

Units are made in various sizes and may be of round, square, or rectangular shape (Figs. 2.38 and 2.39). The master holding die may be constructed for multiples of two, four, six, or eight units and thus may range in over-all size from quite small to quite large. The size of the

units also covers a wide range, round units usually being from 5 to 8 in. in diameter, and rectangular units from 5 in. on a side up to 12 by 16 in.

The construction details of a round unit die for casting three small identical parts is illustrated in Fig. 2.40. These drawings illustrate the type of gating used, cooling water lines, and other features, one of the

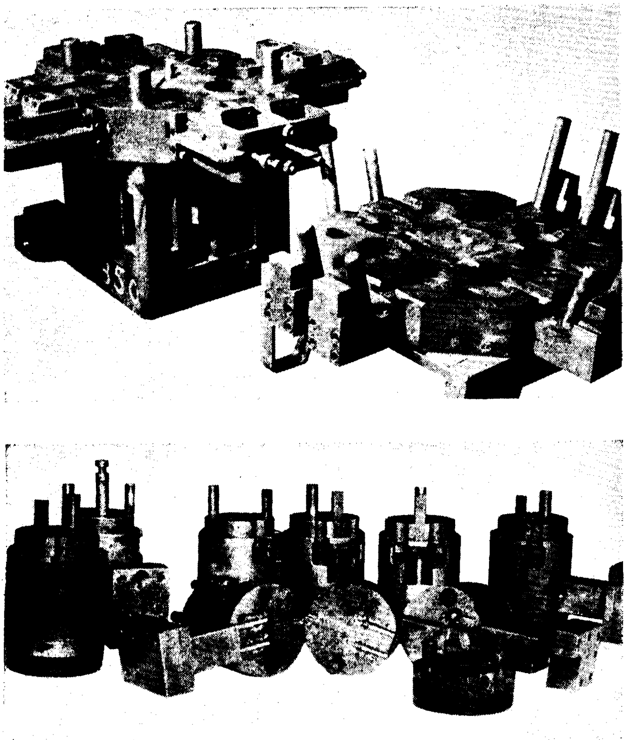


FIG. 2.39. Eight-unit die, with one set (16) circular die blocks. When the gate is ejected, the castings are all attached to it.

most interesting of which is a floating cover that is self-aligning. For round castings, in which cores must be concentric with the outer surface, floating-cover dies ensure a perfect part.

Screws in the cover-die block A hold the impression block with enough tension only to hold it in the cover half. As the die closes, the raised tapered sides of the floating-cover impression block B slide into a depressed section of the ejector-die block C that also has tapered sides. Thus, the cavities in the cover impression are centered over the stationary cores D, and walls of uniform thickness and concentric castings are obtained. Water-inlet tubes E and water-outlet pipes F serve the station-

ary cores with cooling water to prevent the castings from sticking so that the die may be run at high speeds. The sprue is built into the master holding block which holds this unit; only the starting point of the gate runner *G* is shown in the cover die. The gate runner *H* then transfers to the ejector die and into the ejector-die impression.

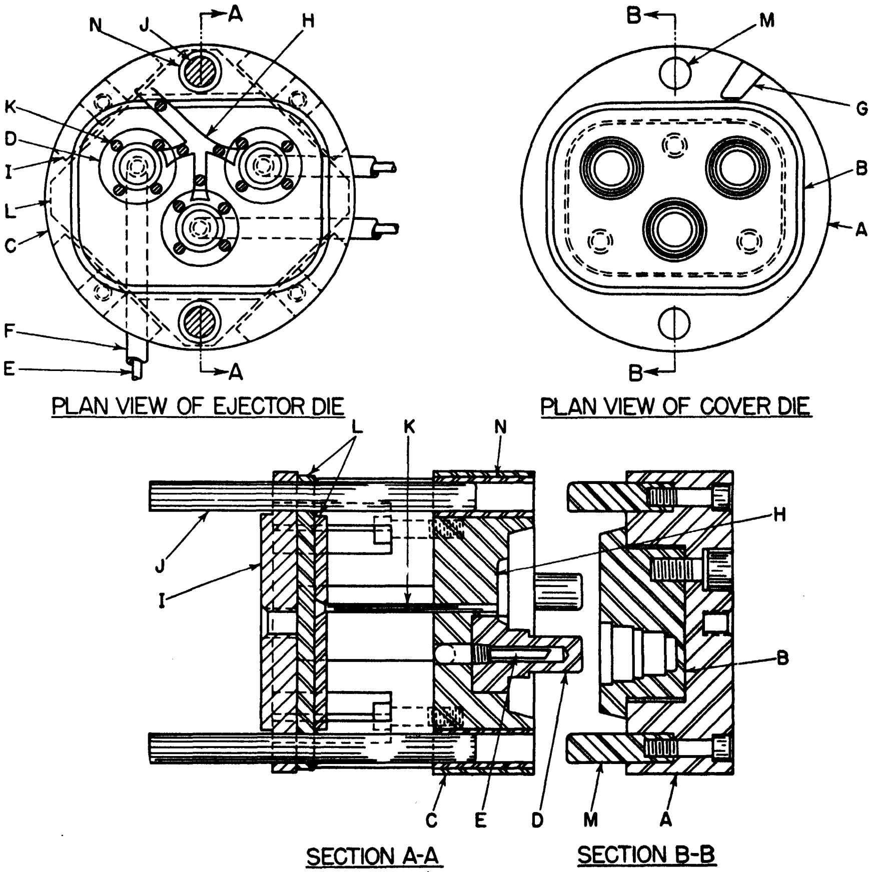


FIG. 2.40. Three-impression unit die having a floating cover that is used to ensure concentricity in the casting.

The ejector-die block is fastened to a cast-iron skirt *I* that is used to house the entire mechanism of the ejector dies. The outside diameter of the die block is ground down to about 1 in. from the parting surface. This ground surface fits into the master-holding-block cavity and forms a tight seal. The rest of the die block and skirt are undercut to provide a clearance in the cavity.

Pusher pins J protrude through holes in the master holding block and are forced out by the master ejector plate as it begins its ejection cycle. Ejector pins K are held securely in the unit ejector plates L, which are welded to the pusher pins. As the master ejector plate moves the pusher pins forward, the ejector pins contact the castings and remove them from the die. All movable parts of the die are returned to the casting position when the pusher pins are contacted by guide pins M as they enter bushings N when the die closes.

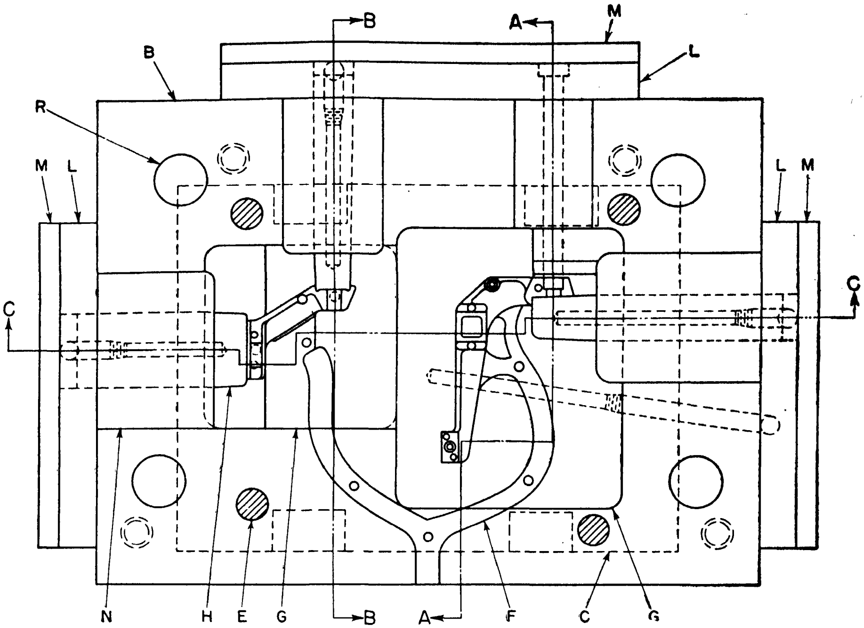
Another type of unit die offering considerable advantages in economy is shown in Fig. 2.41. The holding die of this unit, termed a *standard-unit die,* is mounted permanently to the casting-machine platens, and no die base or core-pull brackets are necessary.

Standard-unit dies, which essentially are only die blocks, are mounted in a master holding die. Core-pull brackets are mounted on the sides of the master holding block, which is then mounted to a die base. The core-pull brackets, master holding block, and die base thereafter remain together. Only the cover- and ejector-die holding blocks A and B are interchangeable within the master holding blocks. Accompanying ejector plates C and D and surface pins E, of course, are included as interchangeable parts since a new set is required with each die. (The position of the pin changes with each change of impression blocks.) Ejector plates are fastened to the master ejector plate, which is fastened to and actuated by a hydraulic cylinder.

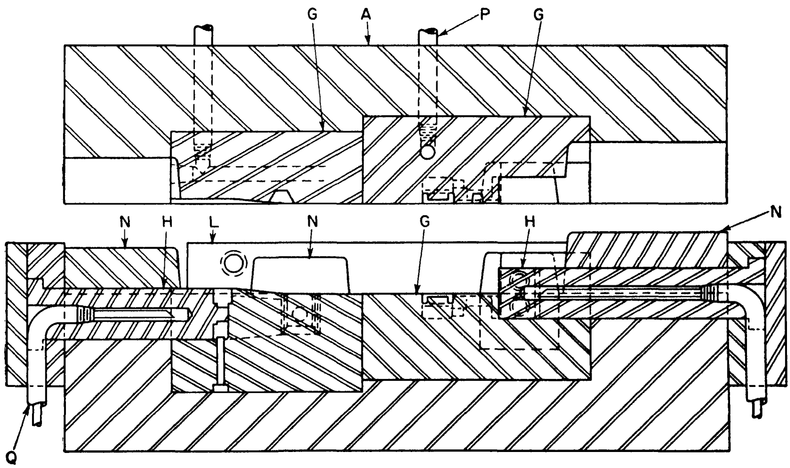
The sprue post (not shown) through which the metal enters the die and part of the runner are built into the master ejector holding block to which is joined the gate runner F in the ejector-die holding block B. Metal flows through each leg of the gate runner and into each impression block G.

Movable slides H and cores I are used to core the casting together with stationary cores J and K. The movable cores and slides are fastened at one end in core plates L and are secured by core backing plates M. In each of these plates there are four screw holes that are used to fasten the slide plates to master slides (not shown) in the master ejector holding block.

The master slides move in and out on grooves in the hydraulic core-pull bracket which is attached to the slide of the master ejector holding block. A hydraulic core-pull cylinder, used to actuate the entire slide, is mounted to the bracket, and its piston rod is fastened in the master slide. Only three sides of a standard-unit die can be equipped with slides. The fourth side is inaccessible because it contains the sprue and gate runner. All slides H move through slide covers N, and cores slide through core bearing blocks O that are used to keep them aligned for casting.

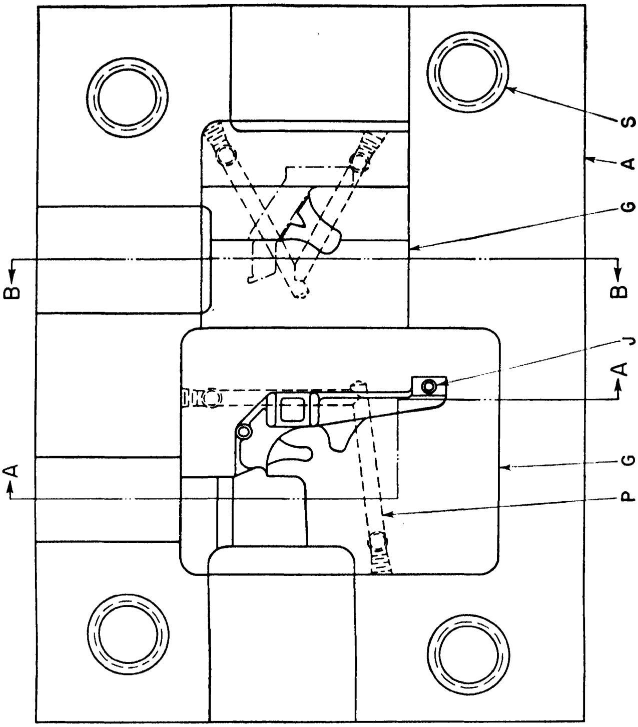


PLAN VIEW OF EJECTOR DIE

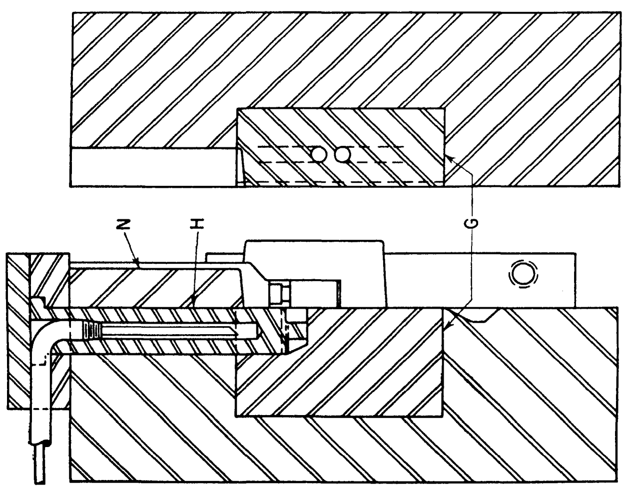


SECTION C-C THROUGH COVER & EJECTOR DIES

FIG. 2.41. Plan and section views of a standard-unit die, which is a multiple-unit die for which no die base or core-pull brackets are necessary. Components are as follows: *A*, cover-die holding block; *B*, ejector-die holding block; *C*, top ejector plate; *D*, bottom ejector plate; *E*, surface pins; *F*, gate runners; *G*, impression blocks; *H*, slides; *I*, cores; *J*, cores; *K*, core; *L*, core plates; *M*, core backing plates; *N*, slide covers; *O*, core bearing block; *P*, water lines; *Q*, single-return water lines; *R*, dowels; *S*, bushings.



PLAN VIEW OF COVER DIE



SECTION B-B THROUGH COVER & EJECTOR DIES

FIG. 2.41. (*Continued.*)

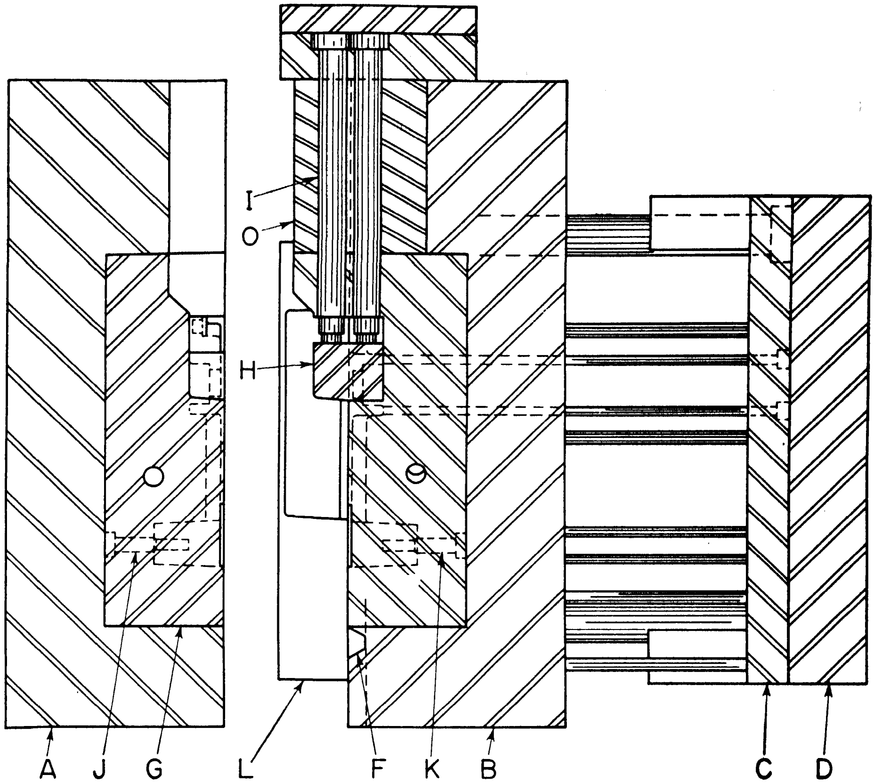


FIG. 2.41. (*Continued.*)

Through-water lines *P* in the cover- and ejector-die holding blocks and single-return water lines *Q* in the slides are used to spot cool the die and help keep it at the proper casting temperature. Guide pins *R* in the ejector-die holding block and guide-pin bushings *S* in the cover-die holding block keep both halves of the die aligned to eliminate "mismatch" in the casting.

GENERAL DETAILS OF DIE DESIGN

Regardless of the type of die that is to be employed, certain fundamental principles involved in its design are of utmost importance. One of these principles is the elimination of stress concentrations. Another is the provision for adequate shrinkage allowance.

Since most die steels inherently have low impact properties or are relatively notch sensitive, every precaution should be taken in design-

ing and building the die to eliminate stress raisers. There are four types of stresses involved that must be considered:

1. The mechanical stress encountered in closing and locking the die
2. The mechanical shock stress involved in making the casting
3. The thermal shock stresses resulting from bringing the molten metal in contact with the die
4. The thermal shock stresses caused by flushing cooling water through the hot die

The mechanical stresses encountered on closing and locking the die are most readily understood, for they can be most readily calculated. This straight compressive stress is not hazardous when the parting line is straight. When there is a V-shaped parting line, however, stress concentrations can become very high at the base of the V, and this should be amply filleted.

A common practice is to use tapered fits on slides and large cores, which are usually locked in place with a wedge lock. When there has been some hammering or deformation of the die, or if bits of flashing have been left in the die, very high pressures can be developed. These often result in the cracking of a die in the corner of the wedge fit or in breaking off of the stopping blocks from the slide. When this type of design is necessary, ample polished fillets should be used.

The mechanical shock stress of making the casting varies with the speed and pressure with which the casting shot is made. The shot stress closely resembles that which might be caused by hitting the die with a hydraulic hammer, the fluid metal transmitting the impact load equally in all directions. It is this high-impact stress that necessitates the use of high holding pressures and core wedge locks. As this stress exists primarily in the die cavity, the points of maximum stress are there. Since the die cavity must necessarily be made to the design of the die casting, very little can be done to decrease points of stress concentration. Careful location of water cooling lines and maximum allowable fillets, however, will aid in decreasing stresses.

The thermal shock stress resulting from almost instantaneous contact of hot molten metal with the relatively cold die surface will cause cleavage cracking as well as heat checking of the die, as discussed in Chap. 6, Die Steels. This generally occurs at sharp edges or corners of slides or near inserts in the die and is most pronounced where the casting is the thickest. The sharp edges become much hotter and therefore more highly stressed than the flat faces of the die. For example, adjacent to an ejector-pin hole the die will form cracks radiating from the ejector-

pin hole. Where a square or rectangular insert is placed in the die, cracks may form in the corner of inserts. These types of stress concentration points are difficult to eliminate, but the use of fillets is helpful.

Thermal shock stresses resulting from flushing cold water into a hot die can be partially minimized by proper design.

Water lines should be so placed that there is adequate metal between the water line and the die surface—preferably over ¾ in. Consecutive water lines should not be placed in such a manner that they decrease the mechanical strength of the die. When it is necessary to make water lines by drilling two holes to meet within the block, care must be taken that a minimum of sharp corners develop. The V-type water line is dangerous to use and has caused many failures, especially in cores surrounded by molten metal. Also, if the water lines are drilled into steel dies with little or no thought given to surface smoothness of the drilled hole, the sharp tool marks left by the drill are dangerous stress raisers. Inspection of a number of blocks has shown cracks to have started at these tool marks.

Apparently, metallurgy has not been able to supply the die designer with a tough die material, and he must compensate for this by careful design to eliminate as many points of stress concentration as possible. In the discussion of the various types of stresses and their control, the use of generous fillets has repeatedly been offered as the solution. Sharp corners are known to be points of stress concentration, and cleavage-crack failures can usually be traced to them.

A sharp corner or notch need not be the intersecting line of two large surfaces of a die, but a small, sharp tool mark will form a notch equally hazardous. Tool marks are especially hazardous when they exist in what is supposed to be a fillet. Tool marks in drilled water lines are serious causes of failure and may well be responsible for much of what is termed *water-line cracking*.

Shrinkage Allowance for Dies.* When a metal cools from a high-temperature level, it undergoes a change in volume which in the casting trade is known as *shrinkage*. The amount that a metal shrinks depends primarily upon its composition, but other factors also may have some effect, especially in die casting. These are (1) the temperature at which the metal is injected into the die; (2) the temperature of the die; (3) the contour of the part; and (4) such factors as the degree of die polish, the presence of a die lubricant, and the injection pressure. The last-named factors are really of secondary importance and usually can safely be ignored.

* See also R. L. Wilson, Shrinkage Allowance in Die Casting Design, *Tool & Die J.*, January, 1947.

Metals. The base alloys used for die casting—zinc, aluminum, tin, lead, copper, and magnesium—have different coefficients of thermal expansion and contraction (see Chap. 7, Die-casting Alloys). When these values are multiplied by the difference between the casting temperature and room temperature, the product is the shrinkage in inches per inch. This value, when multiplied by the length, width, or depth of a casting, gives the total shrinkage.

A casting cools from the outer surfaces inward, however, and there may therefore be a considerable temperature differential between the outer "skin" of a casting and the core, the differential being less in thin sections than in heavy ones. The calculated shrinkage is thus likely to be greater than the actual shrinkage. For zinc-base alloys, for example, the calculated theoretical shrinkage is in the neighborhood of 0.0096 in. per in. of length, while the practical shrinkage allowed by most die casters ranges from 0.007 to 0.008 in.

Dies. Since dies are operated at temperatures of several hundred degrees Fahrenheit but are machined at room temperature, the difference between these conditions must be allowed for in figuring shrinkage. In short, the amount of expansion of the die must be calculated, and this figure subtracted from the shrinkage value previously obtained for the die-casting alloy.

Contour of Part. Another factor affecting shrinkage is the contour or shape of the part. For example, the shrinkage of a part having a free length of 15 in. would be much closer to the theoretical value than if the same part were cored at several points along its length. Estimating the extent to which die restrictions will govern shrinkage is largely a matter of experience, but one approach is to consider the longest free shrinkage length of a casting and estimate the total likely shrinkage with this limitation in mind.

Aging of Alloys. Finally, the aging of some alloys, particularly zinc, causes phase changes that result in changes in volume. For zinc, this amounts to about 0.0007 in. per in. If the casting is large, such a volume change could result in a material change in some critical dimension. This too, then, should be considered when estimating a shrinkage allowance for the part.

As a matter of fact, all the foregoing factors should be taken into account when estimating the shrinkage of a simple or complex casting, especially if it is large in size. For the average die casting, however, some general figures can be established. These are as follows: For zinc-base alloys, 0.005 to 0.006 in. per in.; for aluminum and magnesium, 0.006 to 0.008 in.; and for brass, 0.008 to 0.010 in.

ENGINEERING

Tying together all the previous considerations for making a die—and a lot more besides—is the function of the engineering department. This department is charged with modifying the part (subject to customer approval) to improve castability and to lower part cost.

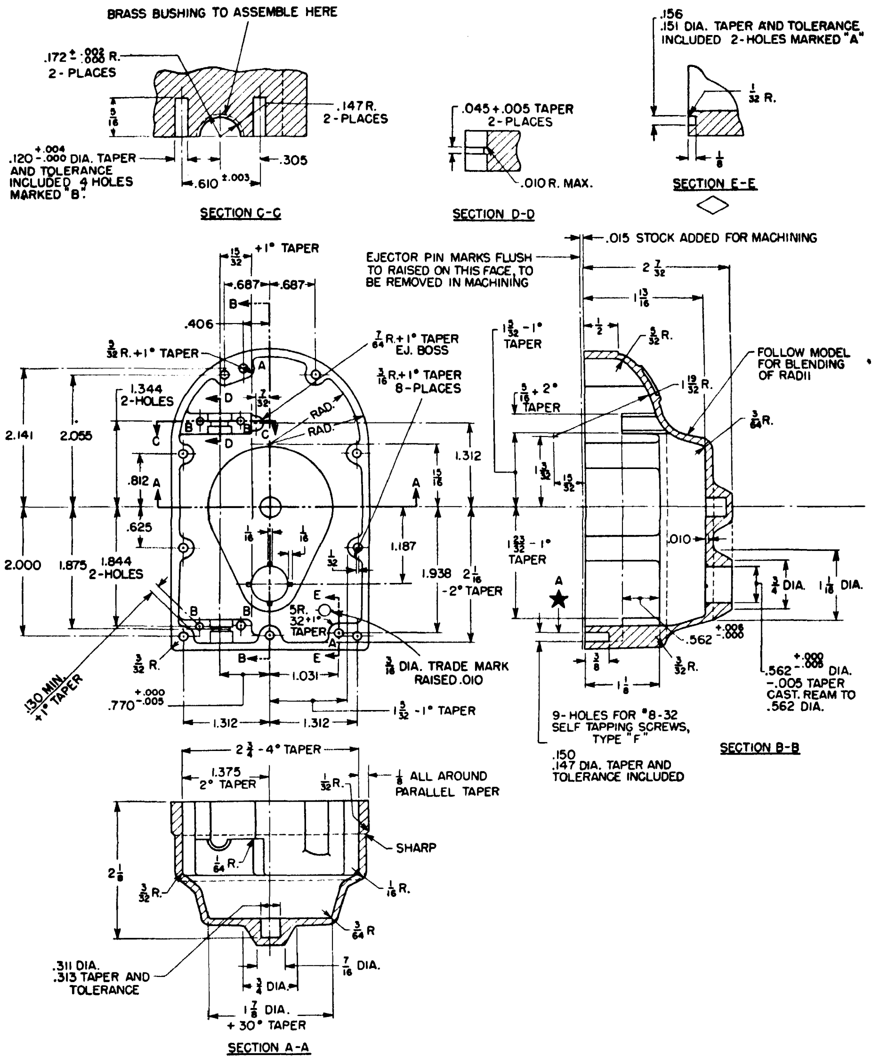


FIG. 2.42. Typical part print made up by the engineering department prior to designing the die.

Part Prints. The first act of the engineering department is to prepare a part print. This is a drawing of the proposed casting that is made to show the customer exactly what he will receive; it also serves to eliminate any misunderstanding, whether it be between the customer and the supplier or between the various departments of the die-casting plant. When this part print (Fig. 2.42) is made, all the changes suggested by the estimating department—elimination of undercuts or cores, changes in dimensional tolerances, or addition of drafts or fillets—are considered and the part changed accordingly, subject, of course, to final approval by the customer.

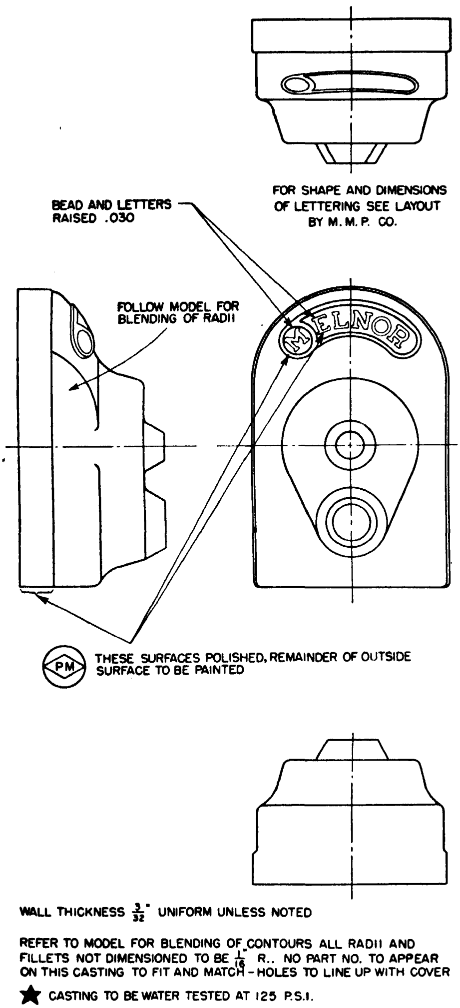


FIG. 2.42. (*Continued.*)

After a part print has been prepared, the engineering department proceeds to lay out the die. A preliminary layout of the die is first made to determine the size and shape of the steel blocks that are required; if blocks of this general size are not available from stock, they then can be ordered.

Die Drawings. The next step is to prepare the die drawings, and there are two methods of doing this: (1) by preparing detailed drawings only of the impression blocks, in which case the diemaker must scale in the rest of the die; and (2) by completely detailing every block and die component. While the latter method is more costly and time consuming, it relieves the diemaker from developing his own dimensions and also makes possible a division of work among several diemakers. For example, a simple part requiring only lathework can be turned over to an apprentice, while other parts that are more complex in shape can be given

to experienced diemakers and specialists or various machines; the parts thus are individually made and finally fitted together. (Detailed drawings must be made for interchangeable dies or for die parts that must be replaced often.)

In any case, certain precautions must be observed and certain procedures followed when the drawings are detailed. These can be listed as follows under the general classifications of Die Layout, Die Bases, Die Movements, Die Gates, and Water Lines and Heating Elements.

Die Layout

1. Check for close tolerances; ask for greater limits if necessary.
2. Check to make certain that the impression is not backward.
3. Star all stationary projections to call them to the attention of the diemaker.
4. Note cores that are to be keyed to prevent turning.
5. Provide for blow across parting lines and slides.
6. Place dowels in the cover die whenever possible. When in the ejector die, place them over the die-base legs.
7. Watch diameter and length of dowels; offset one if die is symmetrical.
8. Use guide pins to equalize any off-center movement.
9. Jig die as centrally as possible. Provide a sufficient number of mounting holes in the cover die and die base.
10. Specify tapped holes spotted from machine in the die base.
11. Check to determine if wedge locks are backed by machine plate.
12. Make sure that side pulls clear the machine bars and that slides and cores can be taken out without removing these bars.
13. Watch die opening and maximum die height.
14. Provide handling holes in die blocks.
15. Provide mounting holes for a parting-line safety device on large dies requiring that the operator lean into the open die.
16. Provide means of loading inserts and of holding them in position.
17. Do not use a hydraulic cylinder for locating inserts.
18. Design the die so that the machine can be operated by one man, if possible.
19. Check steel lists for types of steel to use and steel available.
20. List material on the die drawing.
21. Stamp die blocks with a die number and machine symbol.
22. Specify impression locations in multiple dies.
23. Consider production requirements in terms of the life of the die. Provide for replacement. When necessary, order spare parts when the die is constructed.

24. Make new prints and send copies to the tool and die departments if subsequent revisions are necessary.

Die Bases

1. Use standard die bases whenever possible.
2. Check jigging and bar clearance.
3. Provide a plate on the back of the base if jig holes are unsatisfactory.
4. Place the hydraulic pipe opening for the ejector cylinder in order of preference: (1) on the operator's side; (2) on the top; or (3) on the helper's side.
5. Do not use a die base with small legs on large dies.
6. Use positive stops under the ejector plate.
7. Consider use of a side-mounted hydraulic cylinder and pinion-and-rack ejector movement for heavy ejection.
8. Provide clearance for water lines between the plates and the die block.
9. Use turned heads on core racks.
10. Provide sufficient space between the core and ejector plate for the core-pull movement plus the ejection movement.
11. Screw the core and ejector plates from the back.
12. Place the core and ejector racks to balance the thrust.
13. Provide hanger holes on the bottom of heavy core and ejector plates.
14. Use floating ejector pins when necessary.
15. On long dies, provide center supports to prevent springing of the die block.

Die Movements

1. Make wedge locks short to prevent springing. Use interlocks, with an adjustable hardened plate, on slides and cores subject to considerable blow.
2. Provide compensating locks opposite locks with heavy blow.
3. Provide a limit-switch post for a safety device.
4. Do not use pin pull actuators on dies for casting aluminum, since provision must be made for oiling the cores.
5. Do not use pin-pull actuators on the insert locater.
6. Provide positive stops on double-action movements. Do not rely on friction.
7. Provide a safety device if the ejector pin is under a core or slide.
8. Bullet-nose all pin pulls.

9. Specify spring retainers on pin pulls if they are located on the top or the side of the die where vibration may cause the header to move.

10. Provide clearance around the core body and head in core plates.

11. Provide clearance on side core plates that are not full length. Also, clear plates to parting line.

Die Gates

1. Gate where slight breakouts will not be objectionable.
2. Do not gate the die so that metal shoots into pockets.
3. Provide for air vents and metal overflow.
4. Check with the production department before detailing the gate.
5. Use identical gates for multiple impressions to facilitate trimming operations.
6. Stamp die number, alloy symbol, and steel symbol in runner. (NOTE: Runners must be smooth.)
7. Provide means of rotating (by hand) long thin cores against which metal impinges.
8. Provide a gate hook when gating over a slide.
9. Check whether hook hanging is necessary if the casting cannot be laid in the pan.
10. Check to ensure that metal cannot be shot out of the die if an insert or loose piece is left out when the shot is made.
11. Use standard gate equipment if possible.

Water Lines and Heating Elements

1. Check with the production department before specifying water lines.
2. For zinc and aluminum dies, allow $\frac{5}{8}$ in. between the water lines and all gates, sprue holes, and impressions.
3. Consider water cooling for sprue posts, cores, slides, and sprue holes and under gates and heavy sections.
4. Lower taps of water, fitting the inlets toward the operator.
5. Check the necessity for a heating element.
6. Make pipe taps full depth to prevent leaking. Allow a counterbore when pipes are bent.

DIEMAKING TECHNIQUES

Three general methods of making die-casting dies are used, two of which also are extensively employed in making drawing or forming dies or dies for other operations. These are (1) by machining, (2) by hobbing, and (3) by building a die from laminated steel sheets. Although

a detailed description of the techniques involved in these methods of manufacture are in the province of the toolmaking department and beyond the scope of this text, the engineering-department personnel should have a general knowledge of the various operations in order to design and estimate the cost of the die intelligently.

After the diemaker has thoroughly familiarized himself with the die drawings, which indicate whether the impression is to be machined, he may proceed either by using a model or by sinking the impression directly in the block; if a model is not used, the impression must be laid out on the steel block.

For laying out an impression, the die block must first be thoroughly cleaned and freed from grease and oil, after which the application of a copper sulfate solution or a dye solution is made to the surface. This results in a colored film forming on the steel which will cause the lines made by the scriber point to stand out and become more visible than those made on the plain steel surface.

It is important that two perfectly square adjacent working surfaces of 90 deg be prepared on the block of steel to be laid out. The two 90-deg base lines from which all dimensions are taken are then laid out from these working surfaces with the use of a height gage to which the scriber blade has been attached. Scribed lines of the impression to be cut are then accurately made to within 0.001 in., which in effect is putting the plan view of a drawing on the steel. It may be necessary to employ depth gages, universal angle protractors, and similar devices to establish important working points. The work of measuring and machining to exact dimensions is then started.

If a model of the impression is to be used, it can be obtained either from the customer or from pattern vendors, or it can be made in the pattern shop. When a model is furnished by the customer it avoids unnecessary delays caused by blending and other details that are hard to put on blueprint. This model may be made of wood (Honduras mahogany preferred), metal, or any composition sufficiently hard to hold its shape (lead is unsatisfactory). The model is then set up in what is known as *die position*, avoiding any undercuts. In this position the parting line is created, and a stonelike composition material is poured over it to produce a stonelike duplicating model having a female form. This duplicating model, together with the die blocks, is placed on various duplicating machines, and the cavity or cavities are machined.

Machining. A description of the machining operations involved in diemaking necessarily centers around the major machine tools that are used, one of which is the *rotary-head die-milling machine*. This machine (Fig. 2.43) is so designed that, once a block of steel is clamped in

place, all the machining operations can be accomplished without moving it. The cutter moves in all geometrical directions—in a rotating, vertical, or horizontal plane—so that the relationship of various dimensions between one setup and another is simply a matter of calculation.

In this machine, the spindle that drives the milling cutter is capable of traveling in a vertical plane. The spindle is located in a movable slide

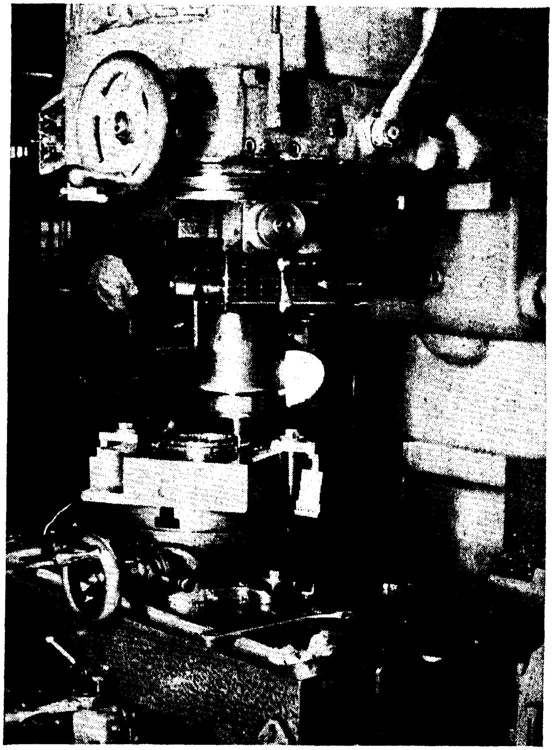


FIG. 2.43. This rotary-head die-milling machine, commonly used to machine the impressions in die-casting dies, is designed so that all operations can be performed without moving the block.

that can be moved off the center point at a distance of 4 in. This slide, in turn, operates in a head that can be rotated in a 360-deg circle, thus inscribing any diameter at which the head slide may be set, up to a maximum of 8 in. By combining these motions with the movement of the table, any geometrical pattern can be made.

When this machine is used to fabricate an impression, a hardened and pointed scriber is inserted in the spindle collet to keep the spindle motionless and at a position on the surface of the steel block of sufficient

depth to draw a hairline. The milling-machine table to which the steel block is clamped is capable of motion in two directions. By moving the various dials on the milling-machine table and the rotary-head slide, and by use of the various combinations of motion inherent in the machine, any pattern can be accurately inscribed in the steel surface. By

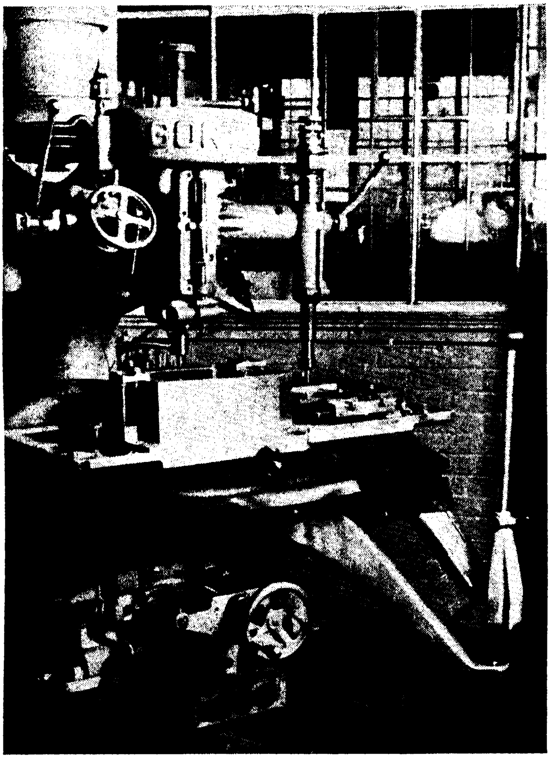


FIG. 2.44. Gorton duplicator, with which the diemaker needs only to follow the contours of a model with a stylus to duplicate the same shape in a steel die block.

noting the dial settings as he moves from one position to another, the diemaker can later come back to the various locating points and start cutting away the steel at the desired places. In this manner he first lays out the shape that he desires to machine. Once this is done, he proceeds to machine the impression.

Other techniques are employed in the process of fabricating dies. The speed head is commonly used on the milling machine as an attachment to attain the higher speeds necessary for the milling of small slots when small-diameter cutters are employed.

The Gorton duplicator (Fig. 2.44) may be used to produce irregular shapes and, as a matter of fact, is specifically designed for this type of work. The cutter and stylus in this machine are also in direct relationship to each other. The model of the piece to be reproduced is clamped on the table of the machine alongside the steel block into which the

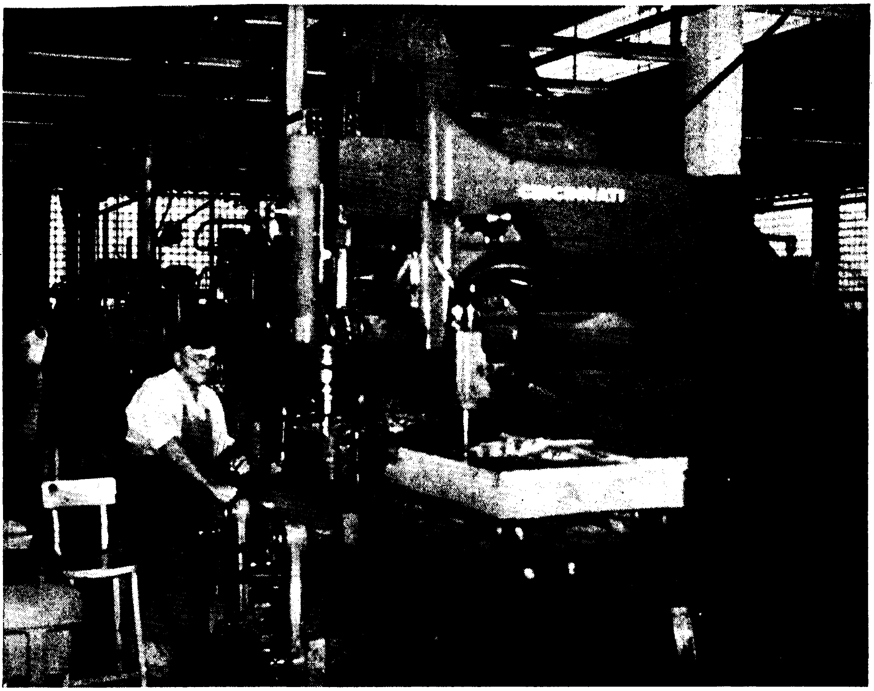


FIG. 2.45. The Hydrotel is also a duplicating machine but, being larger in size, is better adapted to the making of larger dies.

impression is to be cut. The table is free to be moved manually in any horizontal plane, so that the work revolves around and into the cutter. The bulk of steel is first removed with large roughening cutters, and the die is then finished with a cutter of the exact shape and diameter of the stylus, the work being fed to the cutter in degrees of a few thousandths of an inch depth per cut. After the workpiece is removed from the machine, it must be hand-filed and finished to the desired smoothness and polish.

The Hydrotel (Fig. 2.45) is another but larger type of duplicating machine. The application is similar to that of the Gorton duplicator, but the machine is designed for the reproduction of very large die blocks.

On this machine the work is fed hydraulically, and the positions are changed electrically.

The pantograph machine (Fig. 2.46), ordinarily used for the reproduction or engraving of trade names, designs, and part numbers on the impression surfaces, also may be employed for reproducing small, accurate, multiple impressions. The model or master is made 4 to 20 times larger than the actual size of the impressions to be cut. The stylus is secured to the pantograph, which in turn is manually maneuvered to

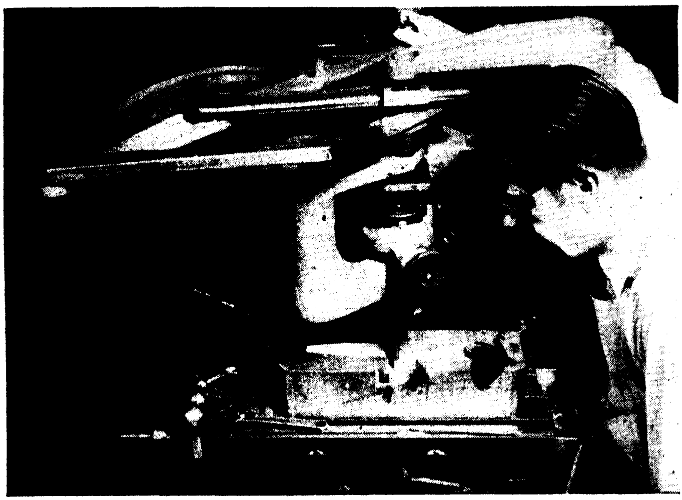


FIG. 2.46. The pantograph is ordinarily used for engraving names, numbers, and designs on the die surface.

follow the depressions cut in the model; the impression is reproduced in the steel by the reduced ratio to which the machine is set and the model or master is made. The templates used in this machine for engraving are made from steel or brass to obtain maximum wear.

The ingenuity of the diemaker is often taxed in many ways in the machining of die impressions. Sections that are inaccessible call for improvisation of methods and the development of ingenious setups with the various kinds of equipment, such as a rotary table on which the work can be clamped and rotated around the cutter to create circular sections, to blend cores into an angle or a straight side, or to perform similar work. The use of the dividing head for the accurate spacing of holes, and the milling of serrations, flat-sided cores, hexagonal, octagonal, or any multiple of flat-sided shapes blending into a radius or into an angle are but a few of the examples of difficult machining operations. All types of lathe operations requiring templates, masters, or followers to

produce seemingly impossible shapes are commonly employed by the highly skilled mechanic.

Hobbing. Occasionally, some shapes are encountered that are too difficult or costly to machine to the required definition in a die. Often, however, such parts can readily be machined in the male, even though cutting them in the female form may be impossible. If this is the case, a male duplicate of the part to be produced can, if made from an alloy steel and if properly heat-treated and finished, be cold-pressed into an

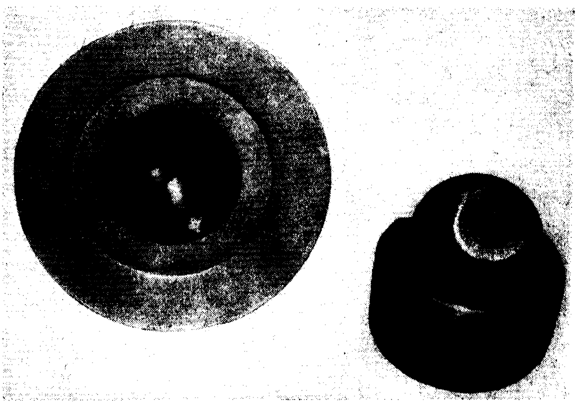


FIG. 2.47. Hob, right, and hobbed impression, left. Hobbing is resorted to (1) for dies having impressions that would be difficult to machine, and (2) for relatively soft dies built for limited production.

annealed-steel die block to form a female impression (Fig. 2.47). This process is known as *hobbing.*

In hobbing, the first step is to prepare the steel blank in which the impression is to be made. The blank should be at least twice the diameter of the largest diameter of the hob. A portion of this steel is polished to a mirror finish. The steel hob is then fitted into a tapered hole of a large-diameter retaining ring, the function of which is to confine the metal as the hob is forced into the blank. The retainer rings are made of alloy steel and are heat-treated to a hardness sufficient to withstand the high pressures involved. With increasing sizes of hobbed impressions, requiring increasing pressures and higher press capacities, the retaining rings must be made proportionally stronger to hold the blanks.

With complicated shapes such as some of those shown in Fig. 2.48, and especially with deep hobbing, the steel becomes so dense and compressed that after reaching a certain depth, the hob cannot be pushed farther. It then becomes necessary to remove the blank and give it a full annealing

heat-treatment, after which it must be repolished and rehobbed for the remainder of the distance. In some cases it is necessary to anneal several times before the impression can be completed.

The hydraulic pressures required for cold hobbing are dependent upon the size or area of the impression to be produced. For small simple shapes, pressures on the order of 500 to 1,000 tons are generally used, while for large impressions, the pressures may reach as high as 2,000

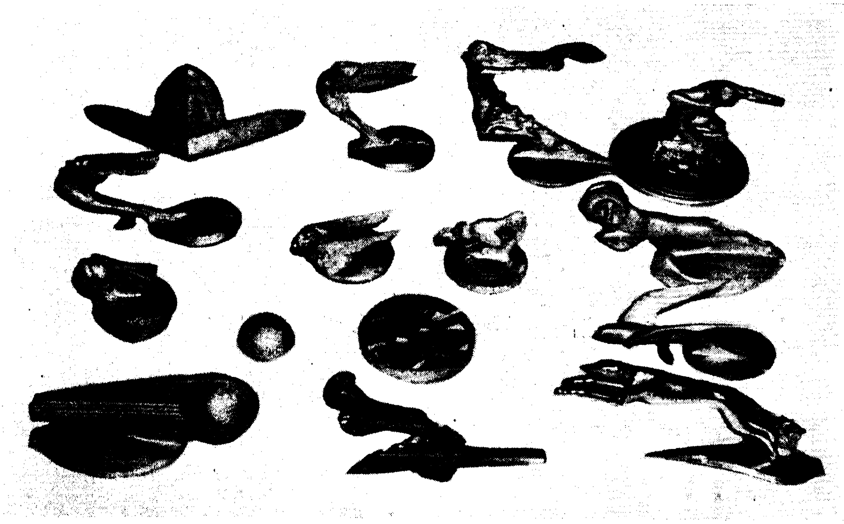


FIG. 2.48. Various types of castings, including many automobile hood ornaments, produced from hobbed impressions.

tons. Hydraulic presses capable of exerting a 3,000-ton pressure are in use.

Laminated Steel Dies. When casting shapes are such that it is impossible to hob or machine the impression in a solid block of steel, the die can be made by building it up of laminated steel sections, each of which contains a portion of the contour of the part. Examples of dies made in this way are those used for the production of typewriter segments, radio condensers, large grilles, and similar parts.

The laminations for such dies are smoothly finished, flat steel sections that are securely doweled and screwed together to resemble a solid mass or block. They are so fitted and doweled that they can readily be separated and reassembled at will, retaining their original size and contour. The sections must be so accurately machined and fitted that, in the casting operation, no metal will enter between the sections and a minimum amount of flash will be obtained on the casting.

Whole impression blocks, cores, or other parts also may be made up of laminated stock.

Inserted Impressions. There are times when it is advantageous to construct the die in such a way that the impression is an insert which is keyed and fastened to the die block—much as carbide inserts are used in trimming and punching dies. Inserts can also be used along slides and cores, around gates, and for other die components subject to wear or casting failure. When these sections of the die fail, they can then be replaced by new inserts.

Other advantages are that (1) steel of the highest quality can be used for the inserts and a lower grade of steel for the die, thus reducing material costs; and (2) when minor changes are made in the design of the casting, only the impressions and not the entire die becomes obsolete. On the other hand, such dies are more costly to build, and the size of dies adaptable to this construction is definitely limited, at least in so far as the impression is concerned. Naturally, inserts can be used around movable die parts in any type or size of die.

Primarily because of their high first cost, however, such dies are practical only for long-running parts; but the higher the melting point of the alloy being cast, the more practical they become for shorter runs.

CHAPTER 3

THEORETICAL AND PRACTICAL ASPECTS OF DIE CASTING

When a die casting is made, a large number of casting variables must be controlled within close limits, and those limits are not always known prior to starting operations on any particular job. The routes over which the injected metal travels in an impression—and other aspects of injection—seldom follow any clear-cut rules. In actual practice, casting conditions are usually varied until the best balance is reached for the casting being produced.

FROMMER'S THEORY

Frommer was the first (in 1932) to offer a graphic picture of the flow of metal in a die and the various factors that govern and are governed by it. His physical and mathematical deductions are based wholly upon practical experience. It is surprising that in spite of the revolutionary progress of die casting since Frommer wrote his book, his general conclusions still seem to hold. (His work was primarily with zinc.)

He started out with a simple die containing a rectangular cavity. Extending partially across the width of one of the small sides of the rectangle was a band gate (Fig. 3.1). By studying the effect of different variables on the casting, he arrived at the following general description of what happens in the die:

The liquid metal enters the die through the gate as a stream with shape and cross section corresponding to the gate. It projects through the cavity until it hits the opposite side of the wall with an impact that causes violent turbulence. A pool is formed on this side of the die, the depth of which depends upon the ratio of stream and die cross-sectional areas. Only a part of the metal runs out of the pool and along the side walls perpendicular to the pool surface. Swirls and eddies are created in the remainder of the metal that stays in the pool by the impact of the incoming metal. These swirls increase in violence as more and more of the incoming metal is retained in the pool by reduction of the flow energy. Finally, all or nearly all the incoming metal stays in the pool and fills the die cavity uniformly across the whole cross section. Only part of the metal that flows out of the pool is chilled and retained on the side

walls. The other part sprays off the side walls into the incoming stream, which again carries it back into the pool. The last voids to be filled are therefore in the center of the die near the gate side. This sequence is shown in Fig. 3.2.

Going more into detail, Frommer elaborates: At the first contact of the inrushing stream with the wall opposite the gate, a part of the cavity next to this side is filled. Depending upon the stream energy, velocity, and area, this takes place under more or less violent impact, with

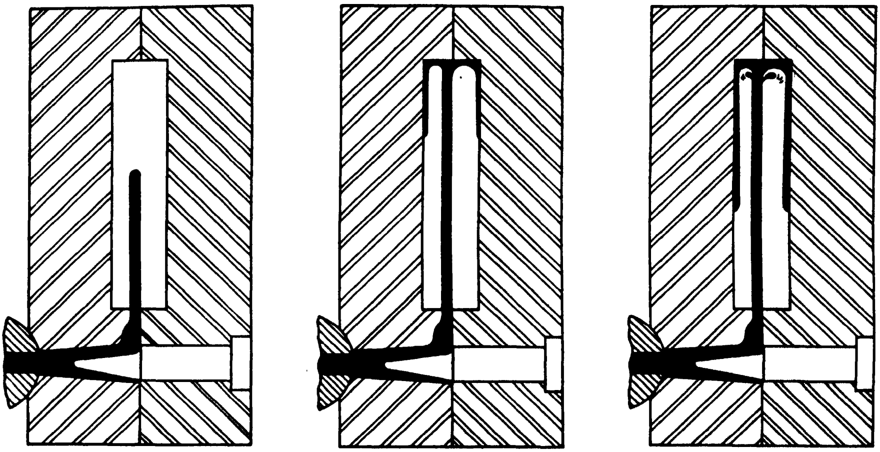


FIG. 3.1. Sketch illustrating Frommer's theories.

accompanying swirls and eddies. The flow energy of the stream entering in the pool is nearly all used up by these swirls and eddies, so that at first the incoming metal is held largely in the pool. As the pool increases and a relatively quiet zone is formed at the back of the pool —and away from the stream of incoming metal—metal begins to flow out of the pool along the two side walls. The speed of these side streams is markedly less than that of the incoming stream, due in part to the loss of energy in the pool and in part to the frictional and cooling effect of the side walls. Since not so much metal leaves the pool as enters it, the pool begins to grow. As more and more metal hits the pool, however, the surface turbulence grows progressively, thus taking more and more of the energy away from the incoming stream. The incoming metal releases most of its flow energy in the front part of the pool, where it hits first. Only a part enters the zone behind it. The more energy behind the stream, the deeper it penetrates. The portion of the metal coming out of the pool and running down the sides becomes less and less until finally only those side streams that were deviated toward the side walls

while the retarding influence of the turbulence in the pool was still small keep on running down the side walls. Frommer calls these side streams "forerunners."

The behavior of these forerunners depends primarily upon their thickness, which in turn depends upon the thickness of the incoming stream and on the friction and chilling action at the side walls. The thinner the side stream, the greater is the effect of friction and chill (aside from variations in die and metal temperature). The speed of these side

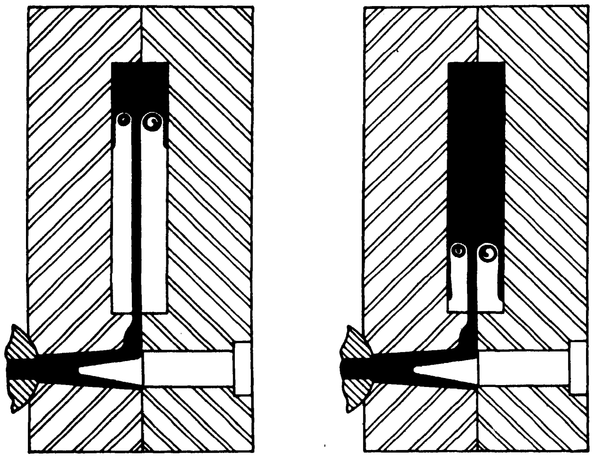


FIG. 3.2. Sketch illustrating Frommer's theories.

streams also decreases with the distance from the pool, so that within a short distance, it is less than that of the advancing pool and is passed by it. It is obviously important that these side streams are not chilled to a point at which, when the hot liquid of the pool meets with them, it cannot fuse; if this occurred foliation would result.

From this general discussion, Frommer proceeds to develop his theory about the effect of the various factors on the casting. Each stream as it passes from the gate to the opposite wall carries on its surface a layer of air, the thickness of which increases with the length and the velocity of the stream. When it enters the pool, it carries the air with it for a certain distance. If the pressure in the pool decreases toward its surface, the air is driven out again, just as when water is poured into a glass. The air bubbles pulled into the water soon rise through the surface because of the decrease in hydrostatic pressure.

The actual distribution of pressure in the pool is described as follows: The pool, as mentioned before, consists of two zones, one near the wall, in which the pressure is quite uniform; and the other above this (nearer

the gate side), in which swirling eddies are formed. In this second zone, the pressure decreases from the periphery toward the axis of the eddies, so that all pressure gradients are directed toward their center. Once air has been dragged into the eddies, it cannot escape; air sucked into the eddies remains in them and rolls with them through the cavity toward the gate. Thus, the eddies, which are useful in decreasing the length of forerunners, endanger the expulsion of the air.

Eddies that are created in the rear zone at the start of impact usually are of minor importance because of their lesser energy. However, if these eddies become large due to excessive turbulence and remain in the rear zone through inertia, the air enclosed in them will probably remain there and not escape.

In line with these considerations, showing that the turbulence in the die cavity and the length of the forerunners increase with the velocity and thickness of the incoming stream and with die and metal temperatures, it should be realized that the pressure exerted on the molten metal in the pool is a function of the square of the velocity of the incoming stream and of the first power of the area of the stream.

However, the increase of velocity of the stream is not directly proportional to the injection pressure. The formula showing the relation of effective injection pressure P and injection velocity V is $V = \sqrt{2gP/D}$ where g is the gravitational acceleration and D the specific gravity of the alloy; V increases only with the square root of pressure. This decrease may be still greater if the air vents do not all function properly. The same formula indicates that jet velocities vary not only with the effective injection pressure, but also with the specific gravity of the cast metal. The velocity V equals $\sqrt{P} \times 1.06$ for magnesium, $\sqrt{P} \times 0.87$ for aluminum, $\sqrt{P} \times 0.526$ for zinc, and $\sqrt{P} \times 0.5$ for brass; in other words, about twice as much pressure is required to obtain the same jet velocity with brass as with magnesium.

Provided that no section of the casting is smaller than the gate, the time of filling a casting is in every case dependent upon the product of the gate area and the speed with which a unit mass of molten metal passes through the gate. A casting can be completely filled within the same time by a larger gate with slower injection speed or by a thin gate with proportionately higher injection speed.

A large gate entails less danger of spraying. If accompanied by a slower injection speed, it also causes less turbulence, less swirling in the pool, and less retention of air. It might cause heavier side streams. Heavy gates have the additional advantage of keeping the metal hot longer than is possible with a small gate.

If, however, the casting is generally heavy but has thin-walled projec-

tions emerging irregularly from the main body, the flow energy into these projections is likely to be decreased by a change in direction of the stream. Air inclusions will then be pushed preferentially into these projections, where they will be solidly surrounded under low pressure by the rapidly freezing metal. Large air voids may result unless the initial velocity of the metal entering through the gate is high—which requires a thin gate.

The apparent density of a die casting (aside from shrink cavities) does not depend entirely upon the quantity of air entrapped in it, but also upon the space occupied by the air. The space occupied by the air depends upon the pressure exerted on the air bubbles. The surrounding metal solidifies, and this densifying pressure in turn is governed by the hydrostatic pressure exerted on the metal when the die is completely filled, provided that the casting has not prematurely solidified in certain sections so that only static pressure exists.

If enough pressure is exerted on the casting while the metal is still liquid, air inclusions can be compressed into a very small volume. Although of beneficial effect on the strength of the casting, the resulting high density is only an apparent density in that the highly compressed air inclusions will rapidly and forcefully expand when the operating temperature is high enough to lower the strength of the metal in the casting to a point where it can no longer withstand the expanding force of the air. This condition is apt to occur when die castings are given a high-temperature heat-treatment or when they are subjected to elevated temperatures in service.

The densification of included air by "after-fill" pressure does not solve the problem; only the correct gate size, injection pressure, velocity, effective placement of vents, and the prevention of spraying and long forerunners will minimize this condition.

With castings of simple design and of a shape not requiring any changes in the direction of metal flow, it is possible under favorable conditions to obtain structures of apparent high density with large gate and high stream velocity, since such conditions make for heavy pressure after the die is filled. The same results, of course, can be obtained with a large gate and lower velocity, or with a small gate and high velocity, if the pressure at the end of the fill is high enough. The latter method has the same densifying effect, and with it there is less danger of trapping air during the filling of the die. Essentially, it is this condition that exists in a cold-chamber machine when the initial stream velocity is throttled down by reducing the flow of liquid into the shot cylinder, and full pressure is developed only when the die is completely filled.

The pressure at the end of the fill helps to force the liquid eutectic into the interdendritic shrinkages between the already solidified crystals of

the higher melting point components. It materially assists capillary action, which in die castings may not be fast enough to be effective by itself. Incomplete filling of interdendritic shrinkages may have more effect on the leakage resistance of a casting than air inclusions or shrinkages, since they are apt to be interconnected.

OTHER THEORIES

Brandt's Theories on Die Casting. Frommer's general concept of the flow of metal, on which he based all his deductions, was challenged by

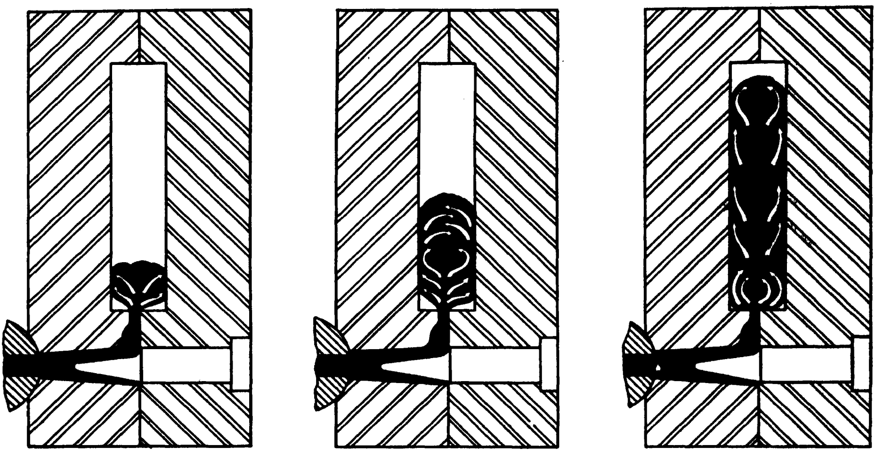


FIG. 3.3. Brandt's setup.

W. Brandt in 1937.* In his investigation Brandt also used a casting of rectangular shape and uniform thickness, but with a gate running the entire width of one of the small sides of the rectangle (Fig. 3.3). At several points, electrical metal contacts were positioned in the die cavity to indicate when contact was made with the liquid metal. The sequence of the closure of the contacts indicated the flow of the metal.

Brandt stated that the incoming stream, corresponding in shape, size, and direction to the gate, spreads out immediately toward the sides that are parallel to and perpendicular to the gate and runs up these sides until both side-wall streams hit the upper wall of the cavity; the streams join at that point. Further, according to Brandt, subsequent streams follow the same course, so that the die is filled from the bottom (gate side) up, whereas Frommer contended that the die is filled from the top side down.

* *Tech. Zentr. prakt. Metallbearbeit.*, vol. **47**.

Koester and Goehring. Frommer was supported by W. Koester and K. Goehring of the Kaiser Wilhelm Institute for Metal Research, Stuttgart, Germany, who employed a rather ingenious experimental setup in their investigation. Two rectangular plates of heat-resisting glass were assembled in a narrow steel frame that served as a spacer and as the side and walls of the cavity. Steel cover plates were placed over the outside of the glass plates. Openings were provided in the cover plates so that an observer could see inside the die. A strong spotlight was centered on the die openings, and pictures were taken with a camera capable of exposing up to 3,500 frames per second.

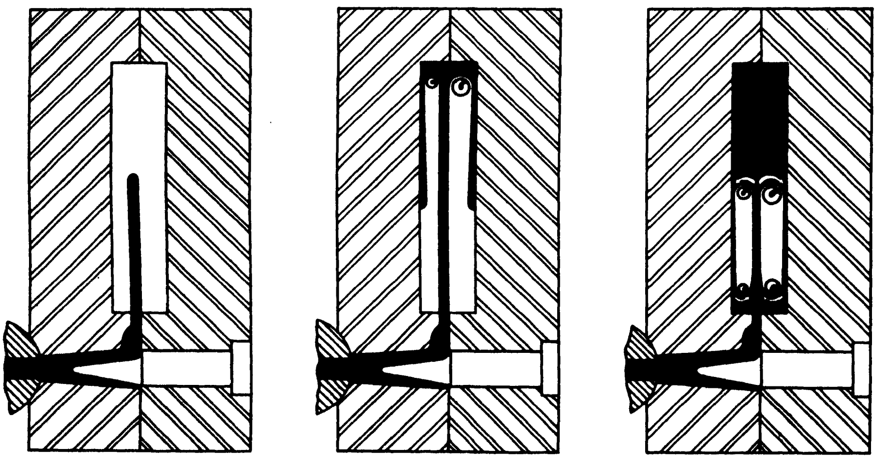


FIG. 3.4. Koester and Goehring setup.

Wood's metal was forced into the die under pressure through a circular gate placed in the center of one of the small sides of the rectangle (Fig. 3.4). In another experiment a circular gate was located near the end of one of the small sides of the rectangle, while in another a band-shaped gate was placed across one of the small sides of the rectangle. An exact duplication of Frommer's gate arrangement (a band gate partially along one of the small sides) could not be used since the stream would have completely obscured the light. Rectangular U-shaped and rounded U-shaped dies were also used in the investigation.

Koester's and Goehring's final conclusions were that the flow of metal into and in the die is basically the same as described by Frommer. The only difference was in the evaluation of the friction and turbulence losses. Frommer maintains that the pool on the side opposite the gate holds back practically all the incoming metal, passes the forerunners on the side walls, and then fills the die. Koester and Goehring contend

that the actual flow is governed to a lesser degree by friction and chilling than claimed by Frommer, so that a shallow pool which contributes to the filling of the die is formed at the gate side of the die by the side streams joining with the incoming stream. They admit, however, to the possibility that these minor differences may have been caused by the use of glass instead of steel and by the fact that the temperature difference between die walls and liquid metal in normal die casting is greater than in their experiments, since the alloys used in die castings have a much higher melting point than Wood's metal.

Koester and Goehring questioned the validity of Brandt's results by pointing out that the sequence of circuit closures may have been affected by spraying and not the flow of the metal. Practical die casters will be inclined to place sympathetic credence in Frommer's theory, since unsuccessful castings generally show that the metal freezes first on the side opposite the gate and that shrinkage is apt to appear close to the gate.

Barton's Theory. H. K. Barton investigated the effect of injection pressure in somewhat more detail than Frommer. He argues that the rise of temperature that takes place in the metal when the velocity of the injected metal is reduced to zero—as happens at the completion of the injection stroke—is expressed theoretically by the equation

$$\Delta T = \frac{P \times D}{Sp \times 854}$$

where P is the injection pressure in kilograms per meter squared, D is the specific gravity of the alloy, Sp is the specific heat of the alloy, and 854 is the equivalent of 2 kg-cal expressed in kilograms per meter. Not all of this temperature rise is manifested immediately; 1 kg of aluminum injected at a temperature of 630°C and at a velocity of 300 meters/sec, *i.e.*, at a pressure of approximately 16,800 psi, is raised suddenly to a temperature of 1130°C at the end of the injection stroke. As much as 40 to 50 per cent of the injection energy may be transformed into heat, with a proportionate drop in the observed velocity of the jet as it issues into the cavity before the gate is reached. Much of the remainder is converted into heat as the jet strikes the cavity wall, and a further loss of energy takes place when the deflected stream merges with turbulent accumulations within the cavity. Only the remaining energy is available to raise the temperature of the whole body of metal as movement in the cavity finally ceases. This residual energy becomes proportionally greater as the injection velocity is raised, for the turbulent masses within the cavity are less sluggish and therefore less able to absorb the energy of the newly injected metal.

Barton claims three distinct effects of raising the injection pressure.

First, by bringing to the injected charge an accession of heat, the influence of small variations in injection temperature on the flow of metal within the die is rendered negligible. Second, a high injection pressure gives more convertible heat at the moment the incoming jet strikes the cavity wall; this raises the temperature and maintains complete fluidity of the turbulent masses that collect at the far end of the cavity. Accordingly, air trapped within these masses can escape more readily than from the viscous masses that are characteristic of low-pressure injection. The third and probably the most profound effect is on the mechanical properties of the casting. Briefly, at the instant injection ceases, all the residual energy of the stream is converted into heat, an effect manifested throughout the whole mass of metal within the cavity. Thus, the temperature of the mass rises while it is simultaneously subjected to the full pressure of the injection system. Incipient stresses arising in the chilled outer layers are liquidated, and a new homogeneity of structure results as the mass once again begins to chill, but now under the influence of full pressure.

Barton's claims have been stated as he formulated them. It is interesting to note that he apparently accepted Frommer's, Koester's, and Goehring's description of the flow of the metal into and in the die. It is problematical whether jet velocity, while the die is still being filled, has the beneficial effect on the swirling turbulence and the absorption and liberation of air that he ascribes to the temperature rise. The metal may be more fluid, but the turbulences will also increase with increasing jet velocity, and the pressure gradient is not apt to be directed toward the surface of the pool any more directly.

He does adduce some valuable arguments in favor of the cold-chamber machine, with its employment of very high pressures. Since the greatest effect of high pressure on raising the temperature is realized when the die is full and when the velocity of the stream is reduced to zero, there would seem to be nothing in his presentation to weaken his arguments when relatively slow injection speed is used for filling the die, with pressure rising to its full high value after filling has been completed.

HOW IMPROPER CASTING TECHNIQUES AFFECT THE PART

Rapid chilling of the die-cast metal results in the formation of a fine-grained structure with attendant increases in strength and ductility. In heavy sections, this effect gradually decreases toward the center of the section. Of course, the more intense the chill, the less the tendency to "forerunners," as Frommer describes them.

On the other hand, premature freezing of thin sections is encouraged

by rapid chilling of the molten metal. This is apt to cause high internal stresses, especially when the shape of the casting involves marked changes in section or when the natural course of contraction while freezing is forcibly restrained by sharp changes of direction. These internal stresses are normally held in check by the strong skin of the casting. They may, however, lead to shrinkage cracks if they are severe, or cause warpage and distortion when the skin is broken by machining or when the casting is used at temperatures high enough to reduce the strength of the skin to a point at which it no longer can keep the internal stresses under control. At any rate, internal stresses are a danger to the physical balance of any casting, because they decrease shock resistance and fatigue strength. Internal stresses may be minimized by stress relief, but this generally results in a loss in mechanical properties. To a large extent the severity of internal stresses also depends upon the modulus of elasticity and on the shrinkage in volume of the metal; under comparable conditions, therefore, aluminum-alloy castings tend to have greater internal stresses than magnesium.

Shrink Holes. Die castings are subject not only to air inclusions, but also to shrink holes, which are caused primarily by insufficient feeding of the casting. For instance, when the metal in the gate freezes before the metal in the casting has had a chance to solidify, volume changes attending the liquid shrinkage cannot be made up by supplying reserve liquid metal through the gate, and shrink holes are apt to occur. Another condition that contributes to the formation of shrink holes is premature freezing of the metal in an intermediate section between the gate and the section in distress.

Gas Holes. Gas holes are another type of defect in die castings. They are distinguishable from shrink holes in that they are smooth and round, whereas shrink holes are ragged and irregular in shape. Gas holes are caused by the release of gases or vapors from the metal as it is cast. These defects occur when the metal is not scavenged after it has been exposed to humid atmosphere and fuel gases in the melting or holding furnace.

Segregation. Segregation in die castings generally appears as a difference in composition between the outer layers of metal, which contain the components that freeze out at the lowest temperatures, and the layers towards the center of the section, which are richer in components that freeze at higher temperatures. The degree of segregation depends upon the thickness of the section and the depth of penetration of the chill. In some cases, especially when the metal is cast at a very low temperature and with low injection speed, primary crystals may come out of the mixture in the well and gate and stick there, so that a correspondingly

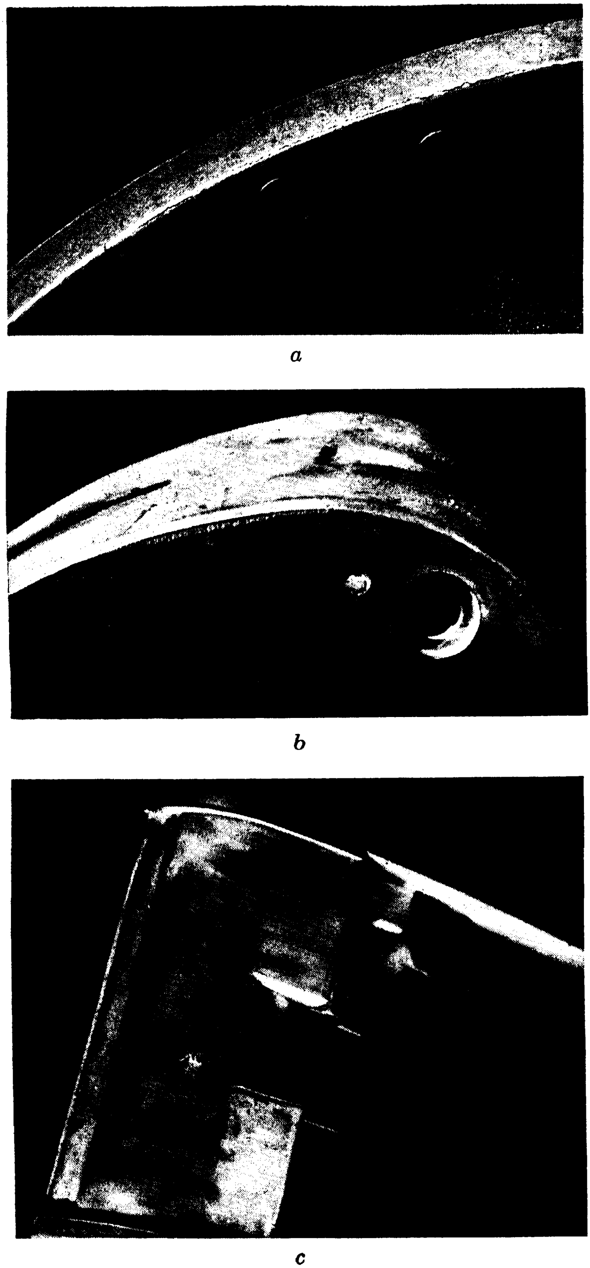


Fig. 3.5. Typical defective castings: *a*, with shrink cracks; *b*, with surface shrink; and *c*, with misrun.

changed composition flows into the die. Variations in composition tend to be reduced by diffusion during the solidification process; however, time is an important factor in the process of diffusion, and a rapid rate of solidification will retain concentration gradients.

Shrink Cracks. Shrink cracks (Fig. 3.5) may occur when the internal stresses created during solidification of the casting are higher than the ductility and strength of the cast metal as it cools from the liquid state. They may also occur when metal around cores is allowed to hug the cores

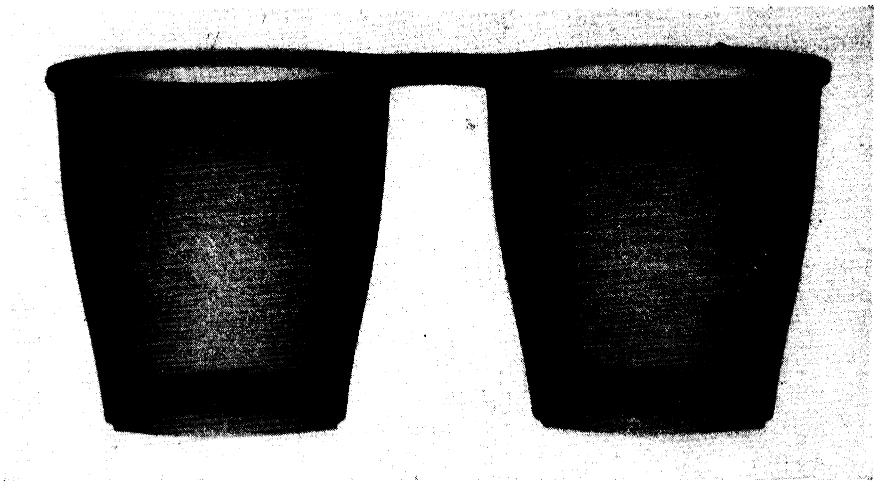


FIG. 3.6. X ray of a magnesium binocular frame showing internal porosity.

too long; if cores are not withdrawn early enough, the gradually increasing shrinkage stresses eventually may become greater than the strength of the metal at these temperatures, and fracture results.

Porosity. Porous, spongy structures occur frequently in connection with oxide inclusions, which may be swept into the casting while laden with gas films. Release of gases may also cause them, or they may occur when metal in the die comes in contact with greases or oil in the die and around cores. Such porous sections (Fig. 3.6) are most injurious, for they decrease impact resistance and fatigue strength and have an adverse effect on other properties.

Cold Shuts. So-called "cold shuts" may occur when the incoming stream divides into several separate jets that fill different parts of the cavity and meet again after traversing individual paths. During their separate travels, these streams lose some heat and develop thin oxide films at their fronts. To ensure complete fusing, it is necessary that these

separate jets retain enough heat to fuse and that they come together under sufficient pressure and velocity to break up the oxide films. It is also important that no air inclusions prevent the junction. Frommer refers to some experiments by Dr. Herner-Rayner, showing that even small impact or other whirling forces are sufficient to tear away the oxide films and to disperse oxide particles into the melt as minute inclusions.

Flow Lines and Blooms. Sometimes, even when all required conditions for complete fusion have been met, it is possible that the extreme

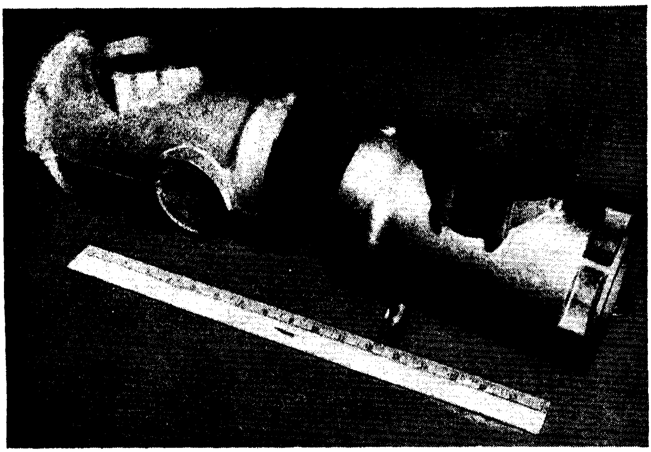


FIG. 3.7. Casting showing run marks or flow lines on the surface. Such defects often are caused by improper die temperatures.

outside layers of separated streams of metal may be sufficiently chilled by the die that they will not fuse when the streams meet. In that case, fine seams or flow lines, generally of minute thickness, appear on the surface (Figs. 3.7 and 3.8). When the temperature of the die is much too low, deep flow lines may appear at the places where divided metal streams meet. This condition generally can be remedied by raising the die temperature. Such flow lines generally are most marked in lead-base alloys and least marked in tin alloys. They usually are of infinitesimal depth and have no effect on the continuity of the casting.

In the higher melting point alloys, particularly aluminum and copper alloys, raised hairlines may also appear as a result of hair cracks in the die due to thermal attack.

Foliations. Small, leaflike metal layers on the surface of the casting, which are only partially fused with the surface of the casting so that frequently they can be lifted by a knife or even a fingernail, occur when a warmer metal stream hits a chilled metal deposit on the die walls before

the die is filled. The hotter metal then penetrates between the die wall and this chilled deposit and forms a thin layer of unfused metal over it; this is known as *foliation*. Foliation may also be brought about by thin forerunners flowing along the die walls, freezing, and then being covered by subsequent streams of molten metal as the filling of the die proceeds.

Hard Spots. Hard spots may occur occasionally, especially in aluminum die castings. They are metallic or nonmetallic inclusions that are swept into the casting along with the molten alloy. Such hard spots

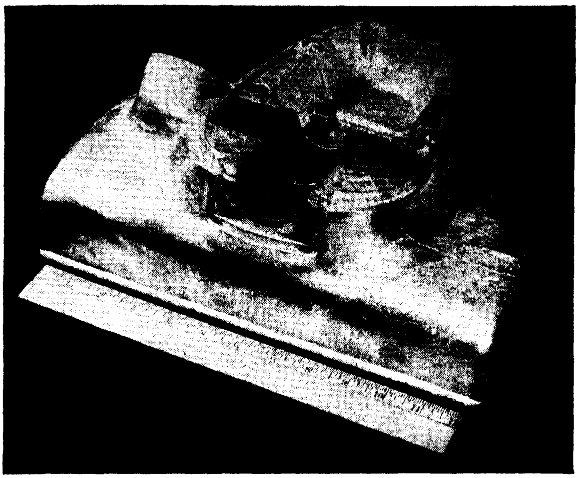


FIG. 3.8. Vacuum-cleaner housing with run marks along the edge (right) and a seam across the top that was caused by a cracked die.

make machining difficult and are apt to have an injurious effect on strength. They can be eliminated by proper metallurgical control, as explained in Chap. 7, Die-casting Alloys.

Surface Draws and Depressions. These defects appear if a condition such as intense, pointed impact or other phenomena cause local overheating of die walls. Such hot spots keep the metal in the immediate proximity hot longer than the layers being deposited over it, so that the latter layers solidify while the layer next to the overheated spot remains in a liquid state. When this liquid metal cools and contracts, it diminishes in volume and forms a depression or draw. This type of defect may also occur if there are many shrink holes or gas holes between the die walls and the metal, or if the metal stream, carrying air with it, is forcibly detoured in direction.

Soldering. Hot liquid metal, when directed for lengthened periods against a spot on the die walls, will tend to cause local fusion of the die

material and the cast metal. Such soldering hinders the ejection of the casting through cohesion of the amalgam with the casting and leaves unsightly spots on the casting when finally it is removed from the die cavity. This usually can be minimized by using the proper die steel with the alloy being cast.

PRACTICAL ANALYSIS AND CONTROL OF CASTING VARIABLES

In the final analysis, the last portion of metal necessary to complete a casting must enter the impression before the portion that entered first has solidified. It therefore follows that injection speed is one of the most important variables in making a casting. Injection speed (the length of time required to inject the metal into the die cavity in cubic inches per second) depends upon several factors. The main ones are as follows:

1. The latent heat of fusion and specific heat of the alloy.
2. The heat conductivity of the alloy.
3. The solidification temperature of the alloy.
4. The die temperature.
5. The heat conductivity of the die.
6. Whether the casting is largely of thin sections or heavy sections.
7. The average distance which the metal must travel to fill the impression.

General consideration of all these points does not necessarily give an absolute value for injection speed; but by using the first four as a means of comparison between different alloys, such as between zinc, aluminum, brass, and magnesium, a theoretical ratio can be obtained that will indicate whether one alloy should be injected faster than the other, all other conditions being equal. As an example, consider a theoretical study of the comparison between zinc and aluminum alloys.

Latent Heat of Fusion and Specific Heat of Alloys. The latent heat and specific heat of zinc and aluminum alloys differ. As shown in Figs. 3.9 and 3.10, zinc has a latent heat of fusion of 43 Btu/lb, whereas aluminum has a latent heat of fusion of 169 Btu/lb. Zinc contains 10.6 Btu/cu in. and aluminum contains 16.9 Btu/cu in. Therefore, zinc must be injected 1.6 times as fast as aluminum, volume for volume, or aluminum should be injected 0.62 times as fast as zinc. (The heat-content curves for magnesium are shown in Fig. 3.11.) Also, observations indicate a relation between the heat curves and the castability of an alloy; "castability" here refers to the ability to fill the impression with the least number of voids, not to whether the alloy solders to the impression. In

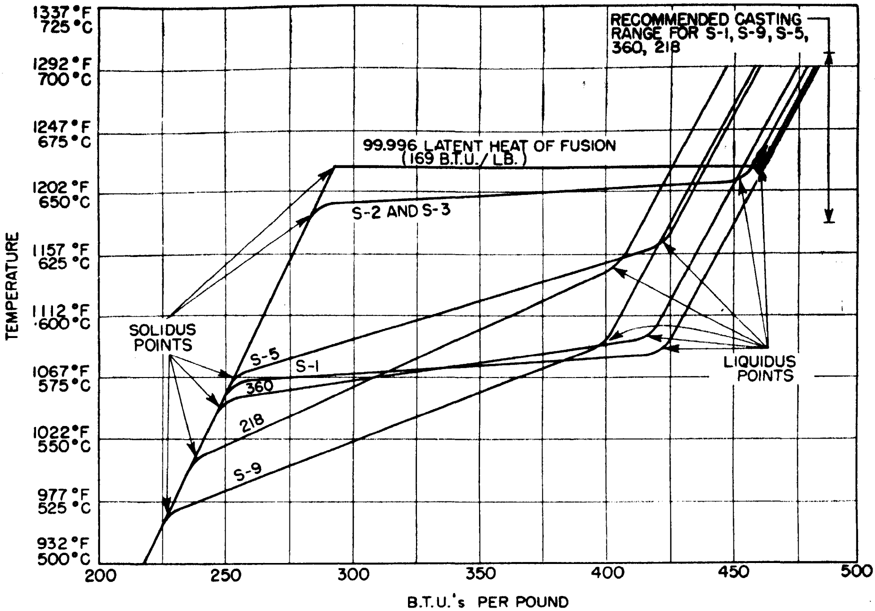


FIG. 3.9. Approximate heat-content curves for aluminum die-casting alloys.

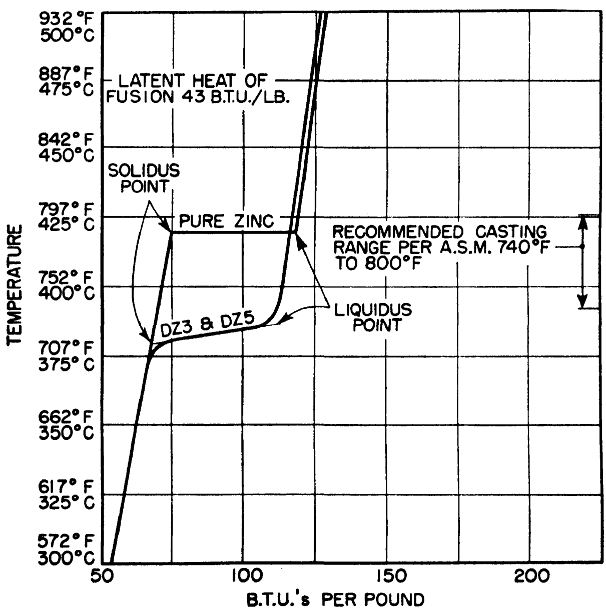


FIG. 3.10. Approximate heat-content curves for zinc die-casting alloys.

Fig. 3.9, the portion of the curve that represents the heat of fusion in the case of 99 per cent pure aluminum is a horizontal line. In the case of Alcoa 218, it is a line lying about 30 deg to the horizontal. The remainder of the alloys lie somewhere between the original line and the Alcoa 218 line. Alloys with nearly horizontal lines are the ones that produce a solid casting with the least difficulty; Alcoa 218 and ASTM SC6 alloys are more difficult to die-cast.

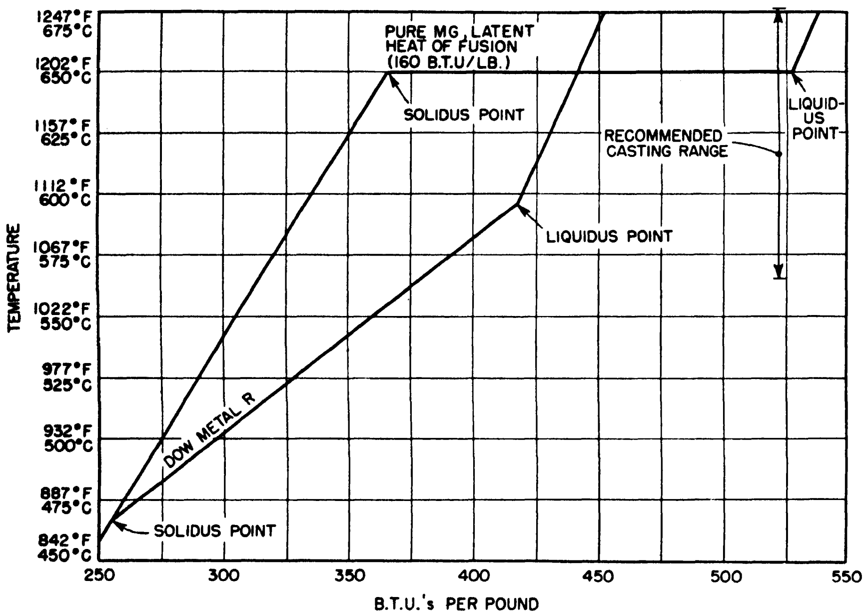


FIG. 3.11. Approximate heat-content curves for pure magnesium and a magnesium die-casting alloy.

This would indicate that the greater the temperature difference between liquidus and solidus, the more difficult it is to produce a solid casting. When casting SC6 alloy, sufficient power must be supplied to the injection mechanism to keep the impression filled while the different constituents solidify and shrink. In the case of ASTM S9 alloy, however, the temperature difference is much less and the alloy more or less freezes "all at once."

Heat Conductivity of the Alloy. The second main point to be considered is the heat conductivity of the alloy. Alloy S9 has a conductivity factor of 0.37; SC6 and alloy XXIII have conductivity factors of 0.27.

This relationship indicates that the S9 alloy should be injected 1.37 times as fast as alloy XXIII.

ASTM S9	should be injected 1.37 times as fast as SC6.
ASTM XXIII	should be injected 0.73 times as fast as S9.
ASTM SC6	should be injected 0.73 times as fast as S9.

Consideration of both of the first two factors then indicates that

S9	should be injected 0.86	times as fast as XXIII.
SC6	should be injected 0.627	times as fast as XXIII.
XXIII	should be injected 1.17	times as fast as S9.
XXIII	should be injected 1.6	times as fast as SC6.
S9	should be injected 1.37	times as fast as SC6.
SC6	should be injected 0.73	times as fast as S9.

When the heat conductivity of an alloy is low, the heat transmission from the hot molten internal portion of the casting to the extreme corners is slow; therefore, the action of "flushing" the entire impression with heat while the casting is solidifying is retarded.

Solidification Temperature of the Alloy. The final solidification point of zinc is 717°F, whereas the final solidification point of aluminum alloy SC6 is 970°F and that of S9 aluminum alloy is 1065°F.

In order to change the latent heat of fusion, the heat conductivity, or the solidification temperature of the casting metal, the alloy must be changed. This cannot be done frequently; *i.e.*, factors 1, 2, and 3 (page 140) are not considered casting variables.

Die Temperature. Die temperature is one of the most important of the many variables in the die-casting process. The work of Werley * on the effect of die temperature on the physical properties of zinc-base-alloy die castings indicates that the best operating die temperature for the casting of the ASTM XXIII zinc alloy is between 350 and 425°F, while for the ASTM XXV alloy a range of from 350 to 475°F is most satisfactory. If the dies are operated at temperatures lower than these, the casting is likely to have a poor surface finish and low impact strength. Similarly, a higher operating temperature will adversely affect the mechanical properties, but not the finish to the same extent.

Close temperature control is equally important in die-casting other base alloys. In so far as aluminum-base alloys are concerned, a good surface finish on the castings is associated with relatively high die temperatures—on the order of 500 to 600°F. Other properties such as tensile strength and microstructure are generally known to be affected by die temperature, although full quantitative information is not yet available. Last, but not least, close dimensional tolerances on a casting can be held

* WERLEY, G. F., ASTM, 1937.

only by maintaining the temperature of the molten metal and the temperature of the die within close limits. It is certain that variations in die temperature will cause variations in dimensional accuracy and the ultimate rejection of a large number of parts by the casting department.

The rate of cooling of an alloy in an impression depends upon the temperature difference between the die and the alloy. If, for example, the die temperature is changed from 400 to 600°F, the injection speed can be decreased approximately 25 per cent.

If the average die temperature for zinc and aluminum is taken as 400°F, the temperature difference between the average die temperature and the solidification temperature of the different alloys indicates the following ratios:

SC6	should be injected	1.8	times as fast as XXIII.
S9	should be injected	2.1	times as fast as XXIII.
XXIII	should be injected	0.557	times as fast as SC6.
XXIII	should be injected	0.477	times as fast as S9.
S9	should be injected	1.165	times as fast as SC6.
SC6	should be injected	0.858	times as fast as S9.

If factors 1, 2, 3, or 4 (page 140) are considered, the following ratios are indicated:

SC6	should be injected	1.13	times as fast as XXIII.
S9	should be injected	1.8	times as fast as XXIII.
XXIII	should be injected	0.89	times as fast as SC6.
XXIII	should be injected	0.561	times as fast as S9.
S9	should be injected	1.6	times as fast as SC6.
SC6	should be injected	0.625	times as fast as S9.

If an average die temperature of 600°F were used for aluminum and of 400°F for zinc alloy XXIII, the ratios (using factor 4) would be as follows:

SC6	should be injected	0.947	times as fast as XXIII.
S9	should be injected	1.47	times as fast as XXIII.
XXIII	should be injected	1.06	times as fast as SC6.
XXIII	should be injected	0.68	times as fast as S9.
S9	should be injected	1.55	times as fast as SC6.
SC6	should be injected	0.645	times as fast as S9.

Considering factors 1, 2, 3, and 4 with an aluminum die temperature of 600°F and a zinc die temperature of 400°F, the ratios (using all four factors) are as follows:

SC6	should be injected	0.594	times as fast as	XXIII.
S9	should be injected	1.265	times as fast as	XXIII.
XXIII	should be injected	1.7	times as fast as	SC6.
XXIII	should be injected	0.795	times as fast as	S9.
S9	should be injected	2.14	times as fast as	SC6.
SC6	should be injected	0.47	times as fast as	S9.

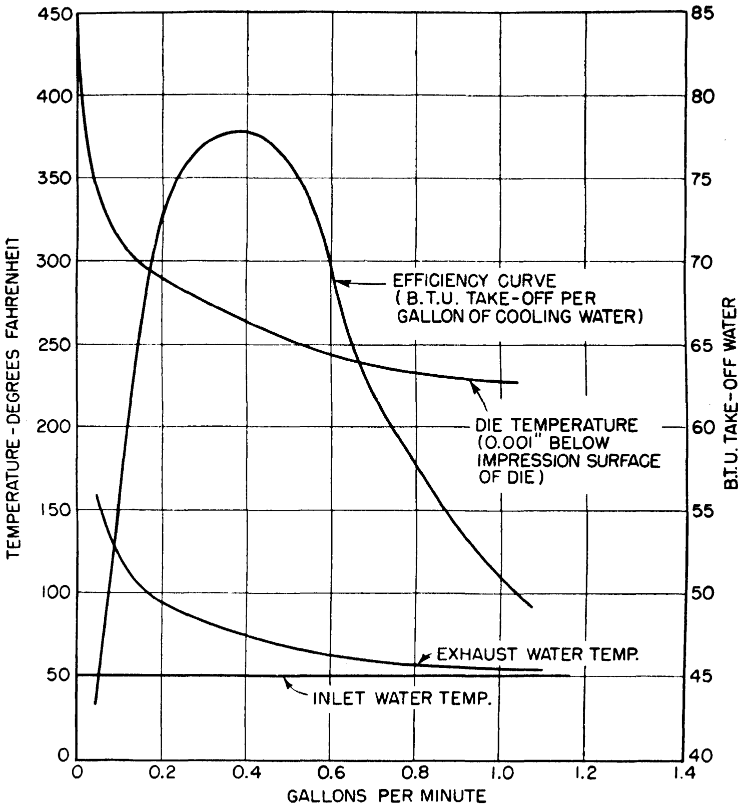


FIG. 3.12. Effect of cooling water on test die block with constant heat input.

Each casting and die has some optimum range of temperature at which the die should be operated. When this temperature range has been found, it should be maintained and recorded on the job record for each part.

The surface temperature of a die during the casting operation can be kept constant within small limits by regulating the operating cycle of the casting machine, thus maintaining a constant heat input. The die tem-

peratures cannot be adequately controlled by a small drilled-hole water-line system (see Chap. 2, Die-casting Dies) since the amount of heat removed by such water lines is a relatively small percentage of the total heat input (Fig. 3.12). These drilled water lines are effective only for spot-cooling or for lowering the temperature generally of a holding die or core or slide, thus ensuring free movement of such moving parts.

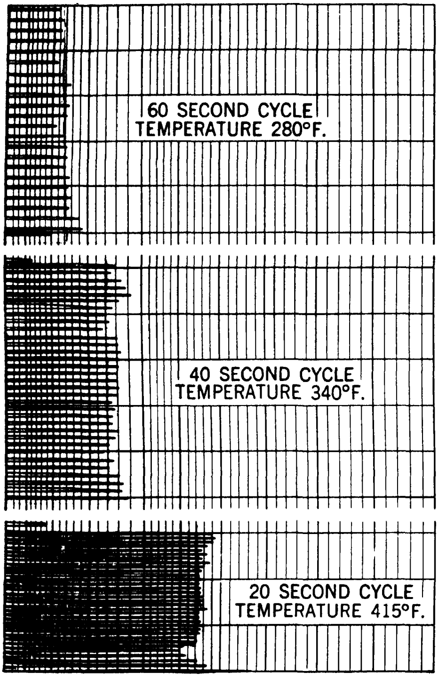


FIG. 3.13. Selected portions of a Ray-O-Tube chart showing how die temperature increases with a decrease in the cycle time of the machine.

Some selected sections of a Ray-O-Tube temperature chart are shown in Fig. 3.13 for castings produced at controlled intervals on the same die as used in Fig. 3.12 with the water cooling. It should be mentioned here that the Ray-O-Tube records only when the die is opened for the ejection of the casting, the pen returning to zero between each casting cycle. In this test a two-impression motor-housing die was used to determine the actual range of die temperatures over which good castings could be made. With a constant flow of water in all lines, this die was run for a short period of time, making castings at measured intervals. As soon as the die temperature reached a constant value, the castings were inspected and a number selected for a dimensional-accuracy check. The speed of the casting cycle was increased and the same procedure followed until a point was reached at which good castings could no longer be produced. The results of these tests are shown in Table 3-1.

Below 300°F, the castings that passed inspection showed some surface defects and were considered questionable. At 300°F and above, all castings passed had a satisfactory surface finish. The range over which castings with a passable finish were made was between 240 and 510°F, which would indicate that an accurate die-temperature control is not necessary to produce castings with a good commercial finish. Rather, it is only necessary to establish a minimum die temperature, which in the

case of this particular die was 300°F. Surface finish, however, did improve slightly as the temperature was increased beyond this point.

TABLE 3.1. EFFECT OF CASTING CYCLE ON DIE TEMPERATURE

Casting cycle, sec	Die temperature, °F	Castings passed	Castings rejected
80	220	0	All
70	245	53	5
60	280	43	3
50	300	52	4
40	340	66	8
35	365	82	16
30	400	91	13
20	415	100	15
15	510	*	

* Satisfactory from a finish standpoint, but most castings showed cracks.

The castings from this test were then measured by production checkers for dimensional accuracy, the measurement being the average dis-

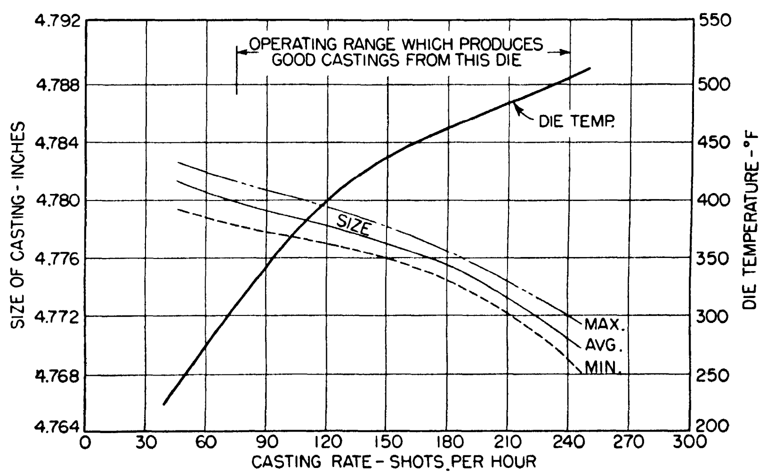


FIG. 3.14. Effect of casting rate on the dimensional accuracy of a test casting.

tance over the outside of two of the four bosses located at intervals around the castings. This was done to catch any errors due to eccentricity. The average size of 20 castings, the minimum size of any casting,

and the maximum size of any one casting were plotted against the casting rate per hour, results of which are shown in Fig. 3.14. All the castings made in the temperature range of 300 to 510°F were good. The average size of a casting made over this range was 4.780 to 4.770 in.—a variation of 0.010 in. From maximum to minimum, the castings measured 4.782 and 4.769 in.—a variation of 0.013 in. This variation is outside the standard tolerance for a 5-in. dimension, which is plus or minus 0.005 in. If, for example, the die temperature were controlled between 350 and 400°F, the variation in averages would be about 0.0025 in. and the variation from maximum to minimum would be 0.005 in. For accurate dimensional control, then, the maintenance of a constant die temperature is essential.

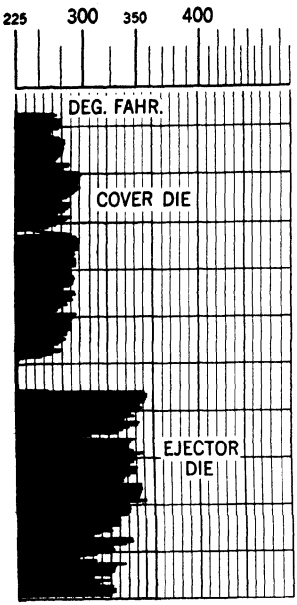


FIG. 3.15. This is a chart of a medium-sized die operating at a metal temperature of 1400°F with an aluminum alloy. The average machine operating speed was 150 shots/hr. This chart shows a very low die temperature for aluminum casting work. It will also be noted that the ejector half, which averages 340°F, is warmer than the cover half, which averages only 275°F.

This chart indicates two undesirable conditions: (1) the cover and the ejector die are quite different in temperature; (2) the general die temperature is far too low for satisfactory operation.

Measuring Die Temperatures. Three basic instruments may be used for measuring die temperatures. These are (1) a thermocouple, which can be inserted in the die; (2) a hand pyrometer; and (3) a radiation pyrometer.

Thermocouple. A thermoelectric bayonet-type thermocouple can be inserted in a blind hole drilled in the die block. It should be located as near to the die surface as is practicable, usually within about 0.100 in. from the die surface. A silver tip of the couple is held securely against the bottom of the hole by spring pressure. This thermocouple is connected with a temperature recorder, preferably one having no appreciable lag.

This method of recording die temperatures has several basic disadvantages: (1) the temperature recorded is only relative, that is, it is not strictly a measure of the temperature of die surfaces but of the interior of the die; (2) the temperature obtained is only of a single spot where the thermocouple tip touches the bottom of the hole; and (3) a hole must be drilled in each die, the location in most cases being selected for convenience rather than for utility since the thermocouple can be inserted only from the

sides of the die blocks. Nevertheless, this method often is useful for recording relative die temperatures.

Hand Pyrometer. The hand pyrometer of the Alnor type is one which is used for the direct reading of surface temperatures of dies by contacting various spots of a die with a sensitive thermocouple.

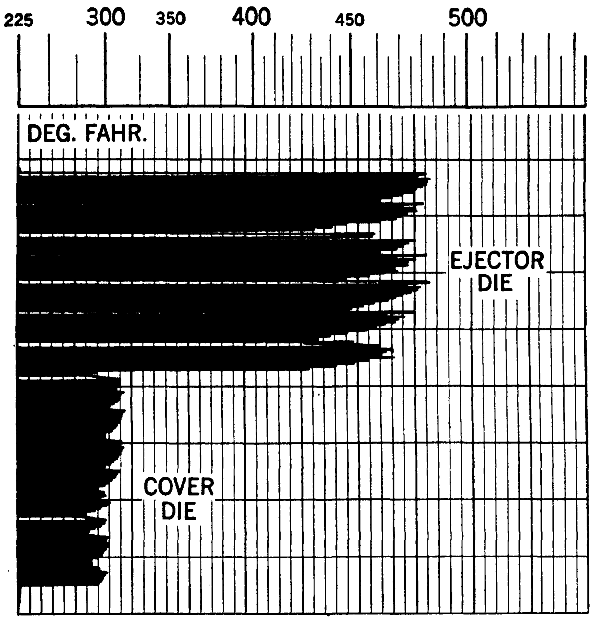


FIG. 3.16. Ray-O-Tube chart of a medium-sized die making a part in ASTM SC6 alloy at a temperature of 1200°F. The machine operating speed is approximately 195 shots/hr.

This is another case where the cover die and the ejector die have widely different temperatures. It will be noted that the average peak cover-die temperature was 300°F, whereas the average peak ejector-die temperature was 475°F.

This die was also operating at subnormal conditions, mainly because of the differential between the cover- and ejector-die temperature. Experience shows that the ejector-die temperature is within satisfactory operating range; however, the cover-die temperature is far too low.

This pyrometer has a special tip which consists of a ceramic material containing a very small coil of thermocouple wire. Its primary use is for spot-checking the temperature of different parts of dies, cores, and slides.

Radiation Pyrometer. A radiation pyrometer is not connected directly to the die. It picks up radiant heat from an area measuring approximately 12 in. in diameter when viewed from a distance of 3 to 4 ft and averages and records this temperature with the aid of an electronic instrument.

The Ray-O-Tube must be set at a constant distance from the die in order to get a true reading. Use of this instrument has proved to be the most desirable method so far developed for recording die temperature. A number of die-temperature charts, obtained with radiation pyrometers, are shown in Figs. 3.15 to 3.22, along with observations on each.

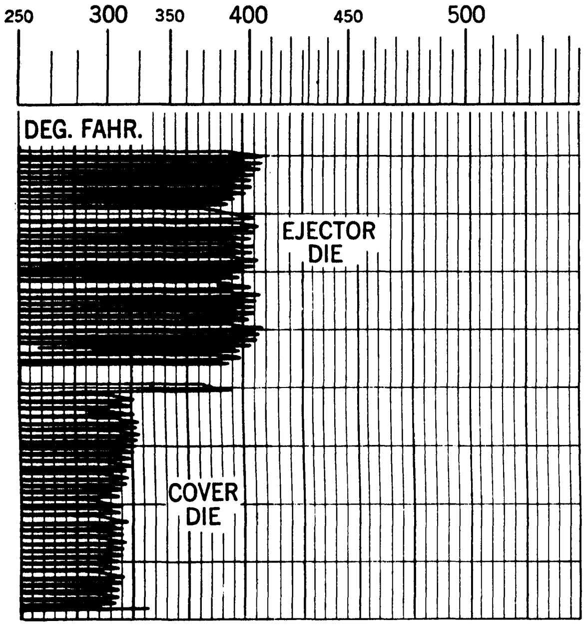


FIG. 3.17. This chart shows the same general operating conditions shown in Fig. 3.16 inasmuch as the cover-die temperature averages 325°F and the ejector-die temperature averages 400°F. The peak temperatures are fairly consistent, and a study of the chart will show that the operating cycle is fairly constant. The previous chart indicates an operational speed of 195 shots/hr, whereas this chart indicates an operational speed of 75 shots/hr. There is a definite cycle of operation occurring about every 15 min, indicating that the machine was stopped for cleaning purposes making it necessary for the die to be heated over again.

The temperatures shown are not necessarily the exact temperatures of the particular impression or section of the die, but rather are an approximation or average over the viewed area. The resultant response time of the recorder and pyrometer is 8 to 10 sec. The highest indicated temperature is shown on the chart about 6 sec after the die opens because the die temperature is slowly decreasing while the recorder is responding.

The operation of a die-casting machine can be followed by studying the Ray-O-Tube chart. Each time the pen advances to the right is an

indication that the die has been opened, and when the line recedes the die has been closed. Variations in peak temperature generally indicate variations in operation, such as oiling the die, holding the die open for cleaning purposes, or poor operating technique. The chart is read from bottom to top, and each main division indicates a passage of 15 min.

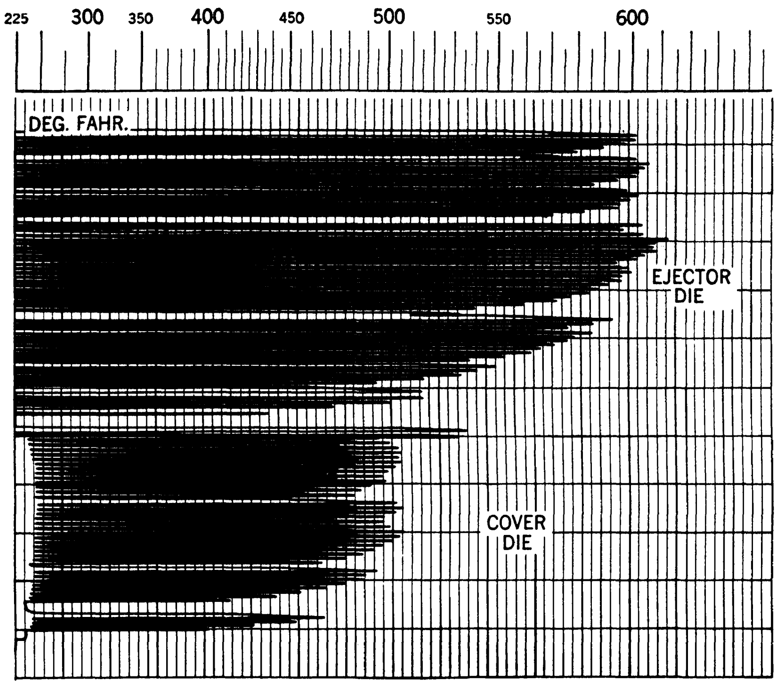


FIG. 3.18. This chart shows a different kind of die-temperature operation. Even though there is nearly a 100° temperature difference between the ejector and cover halves, the average die temperature is 500°F or over. This is a favorable operating condition.

In order to improve this job and enhance the appearance of the portion of the casting formed by the cover half, an attempt should be made to increase the die temperature to equal the cover-die temperature or, conversely, reduce the ejector-die temperature and change one of the operating variables to compensate for it. This die was operating at 90 shots/hr with ASTM SC6 alloy at 1150°F.

Heat Conductivity of the Die. Another factor affecting speed of injection is the heat conductivity of the die. This and factors relating to the size of the casting are very difficult to evaluate. The heat conductivity of the die is consistent regardless of the alloy; however, the type of lubrication or die coating which is used can affect the efficiency of the conductivity, thereby imparting the idea that the conductivity has

either increased or decreased. For example, it has been found that a very thin layer of insulating material such as colloidal graphite makes a considerable difference in the solidification time of the casting. The purpose of and general requirements for a die lubricant are covered in detail later in this chapter.

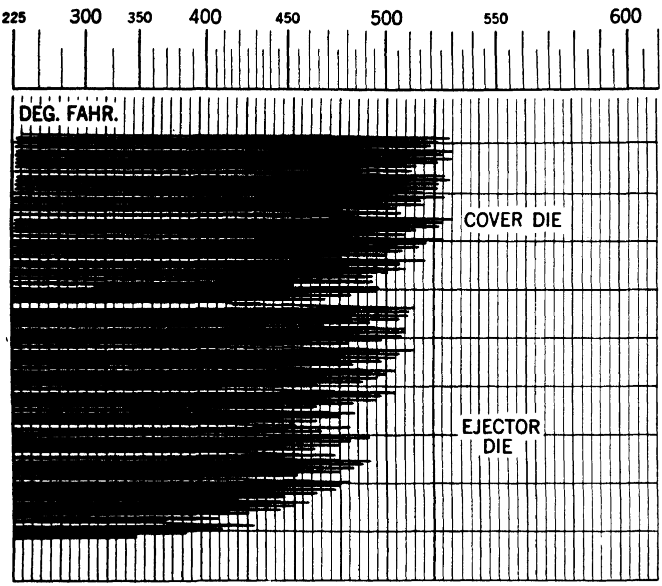


FIG. 3.19. Chart indicating very good die-temperature conditions. This is for a typewriter part being cast at 100 shots/hr using ASTM SC6 alloy at a temperature of 1175°F. The smooth repetition of the lines indicates that the job was operating with little or no mechanical difficulty and the operator was using good technique. The ejector and cover halves are generally of the same temperature and close to an average of 500°F.

An interesting characteristic is noted on the bottom of this chart where the ejector temperature starts at 350°F and slowly increases until it reaches a peak of over 500°F. Over 15 min is required from the subnormal to normal operating die temperature.

Design of the Casting. In so far as injection speed is concerned, castings can be more or less divided into different categories: those that are composed mainly of heavy sections and those which are composed mainly of thin sections. In addition, the area over which the casting is spread —large or compact—also will affect the rate at which the die can be filled. As an example, a casting with thin walls spread over a large area will have to be filled at a faster rate of injection than a heavy-walled casting in a compact area. (In the case of the thin-walled casting, there

may be the same amount of metal present; however, more of it comes in contact with the die surface.)

The sectional composition of the casting generally is of such a complicated nature that it is hard to foretell which section will cause the most difficulty. Sometimes it is necessary to add ribs in order to fill a heavy section through a thin section. Castings of a flat-plate variety are generally made with a relatively high injection speed, causing a small amount

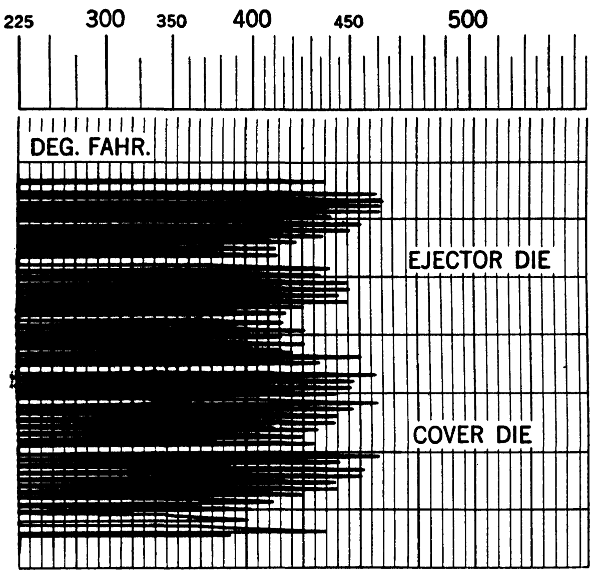


FIG. 3.20. Chart for an average-sized die casting of ASTM SC6 alloy at 1220°F. The average speed of operation is 85 shots/hr.

This chart shows very good operating technique; the rest periods due to cleaning the die or other conditions occur about every 15 or 20 min.

of metal to spread quickly over a large area; in this case, the chilling effect of the die is almost instantaneous. When castings have heavy sections, it is sometimes possible to use a relatively slow injection speed, as long as there are no thin ribs or projections which should be filled by the high-speed method.

Length of Travel of the Metal. Some impressions are elongated to such an extent that it is very difficult to get the metal to the far end of the casting. In cases like this, it is sometimes possible to improve conditions by differential heating of the die (applying heat to the end of the die farthest from the gate). At other times, it might be necessary to use a multiplicity of gates; this should be a last resort, however, because

of the dangers of introducing counterflowing streams of metal. When gates are introduced at different ends of an impression, it is very possible that all of them will not do their expected job.

The number and type of gates necessary to produce a casting should at all times be held to the simplest combination possible. Consider the

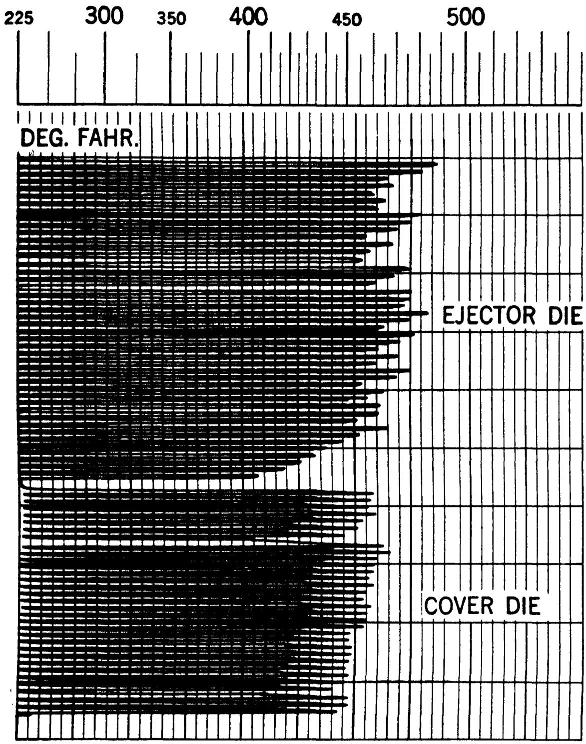


FIG. 3.21. An excellent example of a Ray-O-Tube recording of an aluminum die operating at 72 shots/hr with ASTM SC6 alloy at 1170°F. The average die temperature for both cover and ejector halves is 450°F.

The consistency of the machine operation is excellent and is the general type of curve which should be obtained on each machine.

fact that part of the casting is the gate for another part of the casting. Also, consider that the gate is an opening into the impression through which the metal enters. The gate should direct the metal to selected portions of the impression. The cross-sectional dimensions of the gate should be of the proper proportions and proper area to allow a satisfactory injection speed without causing abnormally high or low metal velocities through the gate opening (see Chap. 4, Design of Die Castings).

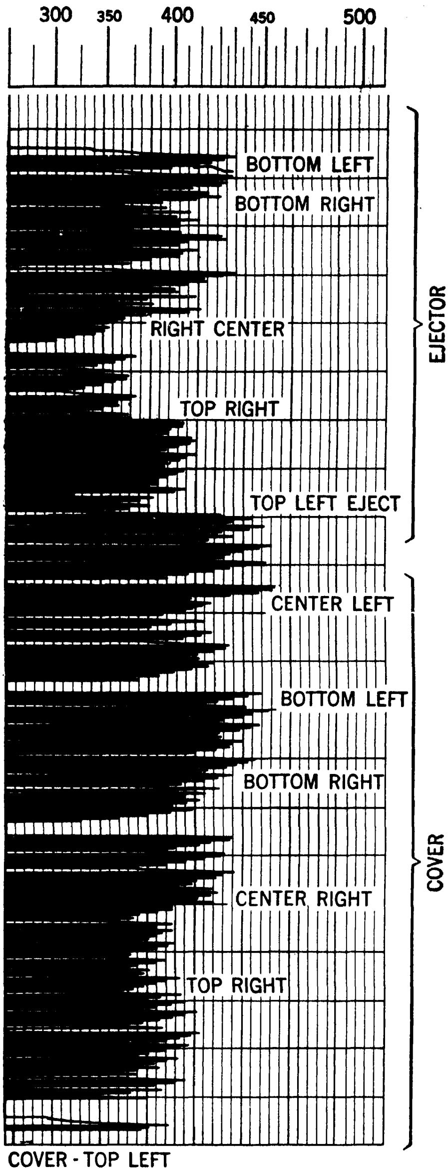


FIG. 3.22. A Ray-O-Tube recording of a six-impression die operating at 130 shots/hr with ASTM SC6 alloy at 1200°F. This chart illustrates the variation in die temperature between different impressions in the same die. The average temperature varies from 325 to 425°F. In other words, a portion of the impressions are operating at the minimum normal temperature. The indications of this chart are sufficient to show why some impressions produce acceptable castings whereas other ones do not.

CORRELATING SHOT SPEED AND PRESSURE

There are three principal ways of controlling the shot speed of a die-casting machine:

1. By controlling the flow of hydraulic fluid in the input side of the hydraulic shot cylinder.
2. By controlling the hydraulic flow in the exhaust side of the hydraulic shot cylinder.
3. By changing the gate opening, thereby changing the metal flow which in turn controls the hydraulic flow.

Other means, of course, can be employed, such as using a large- or small-diameter cylinder to "speed up or slow down the shot." Naturally, this not only changes the speed of piston travel, but changes the force on the metal as well.

Up to the present time, however, there has been no direct correlation between any of those methods and

1. Hydraulic pressures encountered while making a shot.
2. The velocities of the shot mechanism while making a shot.

An effort is being made to correlate these factors in such a manner as to support the existing theory of die-casting practice or furnish sufficient evidence to warrant a new approach. Once this information is correlated the manufacturing department can, by studying the observations on a particular machine, sometimes determine the reason for the production of defective castings.

The apparatus used for this work is as follows:

*Hydrauliscope.** The Hydrauliscope is a cathode-ray oscilloscope equipped with a d-c amplifier. The fluorescent screen on this instrument indicates pressure or velocity as a function of time, or of each other, in a manner similar to the x and y axes on an ordinary graph.

Recording Camera. This is a special 35-mm camera which makes photographs of the Hydrauliscope screen, thereby affording permanent records.

Pressure "Heads." These pressure heads are small mechanisms which, when fastened to any part of the hydraulic system, convert pressure changes into electrical charges.

Travel Head. This is an arrangement for converting the movement of the shot mechanism into corresponding electrical charges.

* Trade name of Aeroquip Corporation.

Miscellaneous. Numerous switches, connections, and controls are necessary to connect the above apparatus properly to give the results described.

A schematic diagram of the shot end of a typical cold-shot casting machine showing how the pressure head, travel head, switches, controls, Hydrauliscope, and components are interconnected is shown in Fig. 3.23. The pressure head is connected to the high-pressure end of the shot cylinder in order to measure the pressure within the shot cylinder itself.

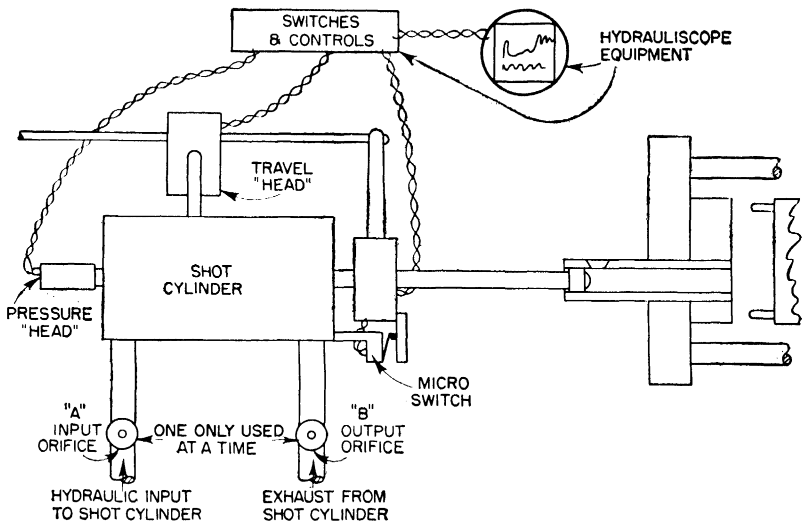


FIG. 3.23. How the Hydrauliscope and auxiliary apparatus are connected to the shot end of a cold-chamber machine.

The travel head is generally connected so that the stationary portion is fastened to the shot-cylinder housing and the movable portion "tack-welded" to the movable crosshead of the shot mechanism. The movement of the crosshead from start to finish produces corresponding indications on the Hydrauliscope screen.

The hydraulic machine valve is generally used to control the velocity of the shot mechanism. However, in order that hydraulic flow might be measured by the same scale in each case, drilled disks are used to meter the hydraulic flow in both the input and the output lines to the shot cylinder. It should be understood, however, that both input and output orifices are not used simultaneously; either one or the other is used, depending upon the test being conducted.

Time vs. Pressure. The changing pressure in the shot cylinder during the period in which the shot mechanism is making a casting is illustrated in Fig. 3.24. In other words, this sketch is a drawing of the typical curve shown on the Hydrauliscope screen when time is indicated horizontally on the x axis and pressure is indicated vertically on the y axis.

The important parts of this curve are lettered a, b, c, and d. (The peak at the beginning of the curve is caused by the starting inertia of the shot mechanism and is of little or no import.)

Section a is that part of the curve caused by the pressures which accomplish the filling of the sleeve and gate runners.

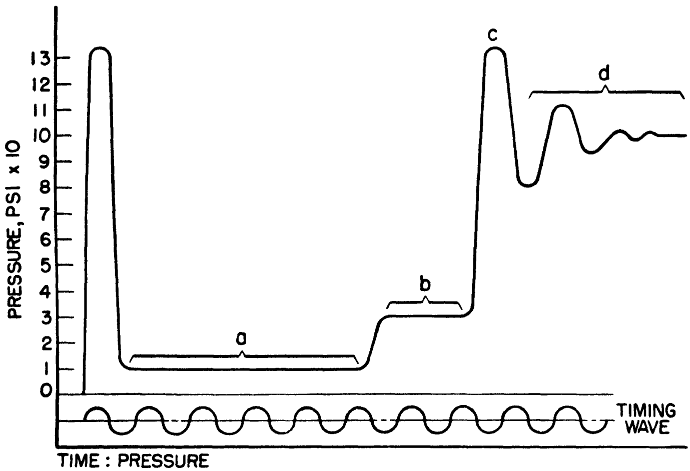


FIG. 3.24. Hydrauliscope diagram showing how the hydraulic machine pressure varies with time when making a casting.

Section b of the curve is caused by the pressures which accomplish the filling of the impression.

Section c of the curve is the peak obtained when the shot mechanism is stopped by the finished casting (many times referred to as "packing in the metal").

Section d of the curve indicates the highly damped oscillating pressures caused by the stopping inertia of the shot mechanism. (This is to be expected with this type of machinery.)

Time vs. Distance. The curve of the velocity of the shot mechanism while making the casting is shown in Fig. 3.25. In other words, this is a drawing of a typical curve shown on the Hydrauliscope screen when time is indicated horizontally on the x axis and distance is indicated vertically on the y axis. The important parts of the curve are lettered k, l, m, and s.

Point k is the starting point for the shot mechanism.

Point l is the stopping point of the shot mechanism.

Distance s, divided by time t, indicates the average velocity of the shot mechanism.

If section m is a straight line, the velocity of the shot mechanism is constant from start to finish. If it is a curved line convex toward the top, the velocity gradually increases and decreases from start to finish (dotted line No. 1). If the curve is concave toward the top, the velocity

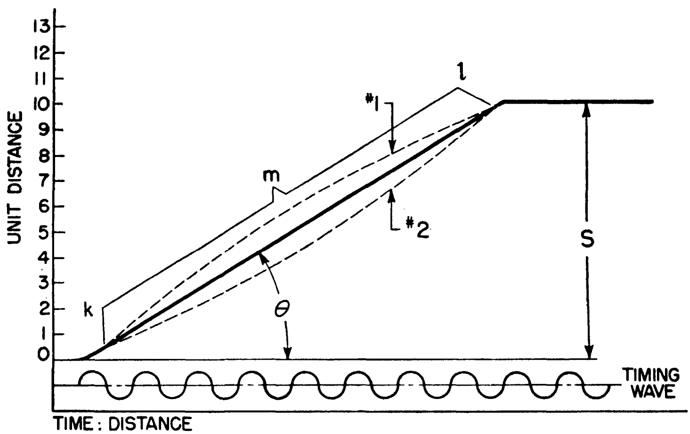


FIG. 3.25. Hydrauliscope diagram showing the relationship between piston travel and time when making a casting.

continues to increase until the end of the shot (dotted line No. 2). If this section shows irregularity, it indicates that the velocity has changed considerably while the shot was being made. Angle θ (slope of line kl) is an indication of average velocity.

Distance vs. Pressure. Figure 3.26 shows the changing pressure in the shot cylinder during the period in which the shot mechanism is making a casting. This is a drawing of a typical curve shown on the Hydrauliscope screen when distance is indicated from horizontally on the x axis and pressure is indicated vertically on the y axis. Important parts of the curve are lettered a, b, c, d, and s. (The peak at the beginning of the curve is caused by the starting inertia of the shot mechanism and is of little or no import.)

Section a is that part of the curve caused by the pressure which accomplishes the filling of the sleeve and gate runners.

Section b of the curve is caused by the pressures which accomplish the filling of the impression.

Section *c* of the curve is the peak obtained when the shot mechanism is stopped by the finished casting.

Point d of the curve corresponds to *section d* in Fig. 3.24. It shows up in this manner because the shot mechanism has stopped moving.

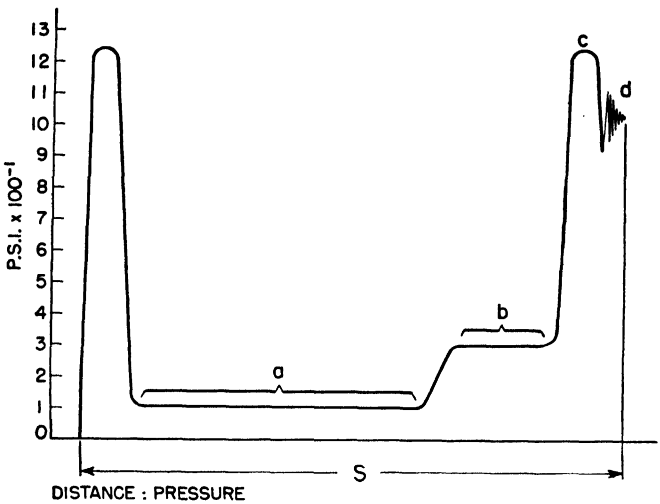


FIG. 3.26. Hydrauliscope diagram showing the relationship between piston travel and pressure when making a casting.

Typical Hydrauliscope Records. Some typical records obtained from Hydrauliscope hookups to cold-chamber machines are shown in Figs. 3.27 to 3.29. Two hydrauliscope pictures for two different dies are shown in Fig. 3.27. The picture on the left side was made from die No. 1 and shows a conventional aluminum-shot picture. The picture on the right is made from die No. 2 and is also a conventional shot; both have a sweep time of 1 sec. Die No. 2 was making a considerable amount of scrap in comparison to almost perfect production by the other die. Die temperatures were comparable, and other visual conditions were such that it might be said that the two dies were operating under the same conditions. An inspection of the two pictures on this slide will show considerable difference in the plateau section. Die No. 2 shows a higher and longer plateau. When the length of the plateau of die No. 2 was made to agree with the other die, the pressure was found to be higher than that then shown. This indicated that the gate in die No. 2 was faulty; probably the feeder was too small.

Two pictures made on two electric-motor end-bell dies are shown in Fig. 3.28. Both dies use a $2\frac{1}{4}$-in.-diameter plunger. The die for the left-

hand picture has a 6-in.-diameter shot cylinder and the other has a 3-in.-diameter hydraulic shot cylinder. The plateau in the left-hand picture is not visible; however, the plateau in the right-hand picture shows a

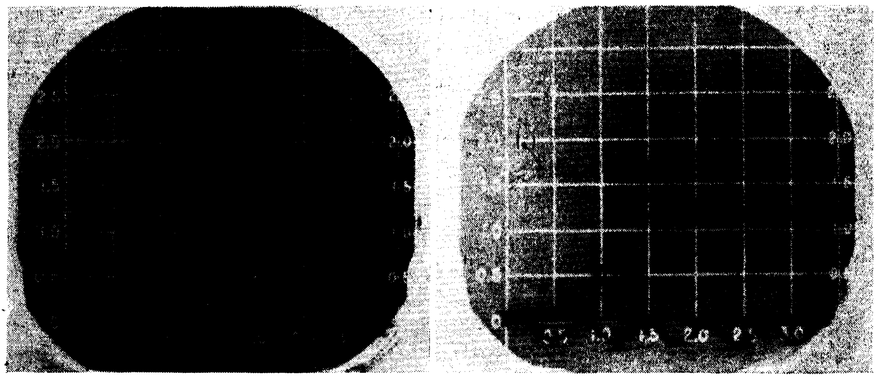


FIG. 3.27. Hydrauliscope pictures for two different aluminum dies, one of which (right) was producing faulty castings.

pressure of about 200 psi. The shot-plunger velocity was equal in both jobs. The object of this experiment was to determine whether, when the velocities were equal in both cases, it would be possible to make

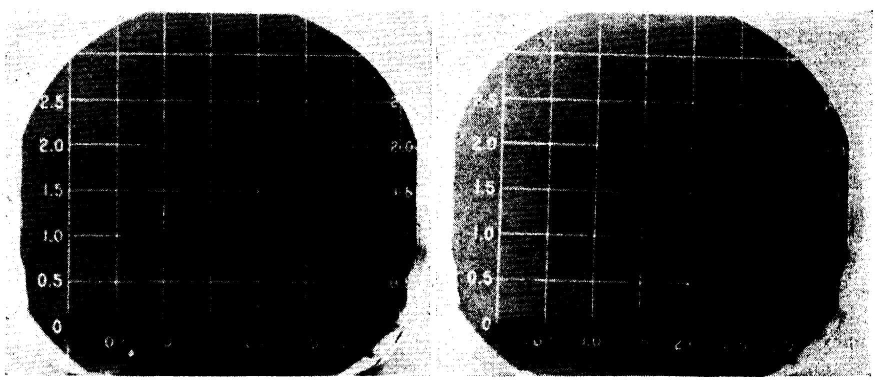


FIG. 3.28. Hydrauliscope pictures for two electric-motor end-bell dies, one on a machine with a 6-in.-diameter shot cylinder (left) and the other on a machine with a 3-in.-diameter shot cylinder.

acceptable castings with a smaller hydraulic cylinder than generally employed. The results of an inspection analysis showed that a 6-in.-diameter shot cylinder produced less than 2 per cent rejects, whereas the 3-in.-diameter cylinder produced nothing but rejects for a period of

over 2 hrs. It should be pointed out that in the case of the right-hand picture the peak injection pressure on the metal was 1,950 psi, and in the case of the 3-in. shot cylinder the peak injection pressure was 7,920 psi. It is quite evident that there was not sufficient metal pressure to fill out the impression. If the velocity of injection were increased so that in the case of the 6-in.-diameter cylinder the impression is filled with metal before it becomes solidified, the plateau for the 3-in.-diameter cylinder would be very high. It might approach the hydraulic line pressure, in

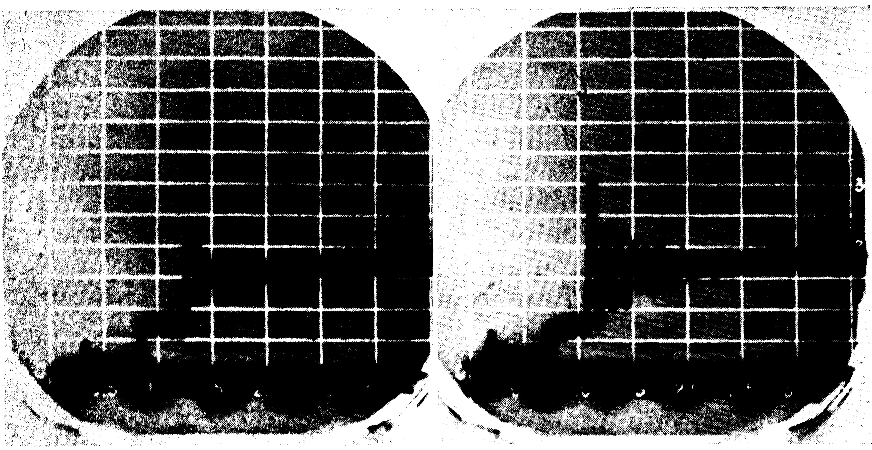


FIG. 3.29. Two Hydrauliscope pictures for a casting produced by automatic ladling (left) and by hand ladling (right).

which case there would be no available power remaining to "pack the metal into the impression" at the end of the stroke.

Finally, two Hydrauliscope pictures for a tote-box casting produced on a 48-in. machine are shown in Fig. 3.29 (casting metal was S9 aluminum). Both pictures were made with a sweep time of 1 sec and a timing wave frequency of 5 cycles/sec.

The left-hand picture was made with automatic ladle operation. The right-hand picture was made with hand ladle operation. All other conditions on the machine were the same in both cases. Some of the principal differences between the two pictures are readily recognized. The plateau in the picture made with hand ladling is higher and longer than the plateau in the picture made with automatic ladling. The peak pressure at the end of the shot for hand ladling is much more than the peak pressure for automatic ladling. This would indicate that the plunger came to a more abrupt stop in the case of the hand ladling than in the case of automatic ladling.

The same casting was being produced in both cases. The same cubic content of impression was being filled in both cases. As previous experience shows, the velocity of the shot plunger depends mostly upon the setting of the hydraulic shot valve; therefore, it is reasonable to assume that the plunger velocity was approximately the same in both cases. The obvious answer to these two pictures is that more metal is being introduced into the impression in the case of the automatic ladle than in the case of the hand ladle (because the plateau is longer). Upon investigation, it was found that the average weight for the hand-ladled casting was 9.42 lb, and for the automatically ladled casting 9.65 lb, showing an increase of approximately ¼ lb per casting.

DIE LUBRICATION

One other important subject should be included under die-casting practice: *die lubrication.* The primary function of a die lubricant is to promote the formation of a thin fluid film between the surfaces of the die and the casting, thus preventing the molten casting metal from melting the die surfaces and forming alloys of iron. Otherwise, these alloys—iron-zinc, iron-aluminum, or others—would cause early failure of the die. If such alloying does take place, the castings tend to stick in the die, thus interfering with the ejection operation and often resulting in bent or distorted castings. Also, the surfaces of the die may show what is known to the trade as a "soldered" condition, so that, if appearance is important, the casting must be cleaned up in some subsequent operation.

Lubricants also are used on moving die parts such as slides, cores, and ejector pins to prevent seizure, galling, and wear. Improper lubrication of these components has the same effect as improper lubrication of the die surfaces, namely, early die failure and decreased casting production.

The Ideal Lubricant. Although there are many particular types of die lubricants that are used with each of the die-casting alloys, one lubricant is being sought that could be used for all alloys. The specifications for such an ideal lubricant might be as follows:

1. It should be satisfactory both for the die surfaces and for the moving die components.
2. It should form a tight adherent film on the die surfaces—one that could not be removed by contact with the high-pressure molten alloy.
3. It should require a minimum number of applications in a given time. Obviously, the more times an operator has to apply a lubricant, the less will be his production. If a lubricant need only be applied once

in, for example, 10 or more casting cycles, there would be less delay in the production schedule than if the operator had to lubricate once in 5 or less cycles.

4. It should have good surface coverage and be capable of being spread rapidly and uniformly over the entire die surfaces and recessed area.

5. It should not stain the die castings. The effect of some lubricants is not only to promote a poor surface finish on the casting, which in turn gives rise to poor mechanical properties, but also to stain the castings. This stain must subsequently be removed from the casting, usually at considerable expense, and very often stained castings must be rejected and scrapped.

6. It should not attack the die steel. Experience has shown that some saponifiable oils containing fatty acids or glycerides of fatty acids break down at elevated temperatures, thus promoting the formation of more active acids (formic and acetic) that readily attack steel surfaces.

7. It should not fume excessively, give off toxic or objectionable gases, cause dermatosis, or otherwise affect the health of the machine operator.

8. It should not congeal or cake, or build up in recessed corners or on die surfaces.

9. Finally, it should be of reasonable cost. Since large quantities of die lubricants are used, this is an important consideration.

Many proprietary lubricating mixtures are on the market, but most, if not all, of these fail to meet the requirements of a suitable, general-purpose lubricant. However, such substances as the silicones, the ucons, some fluororganic compounds, and mixtures of these with other materials are being investigated and may eventually prove to be the solution to this problem.

Molybdenum sulfide (MoS_2) has lubricating qualities equal to or superior to colloidal graphite and has less tendency to stain the castings. It has excellent possibilities as a general die lubricant, but awaits the development of a more suitable carrying vehicle. At present, the ability of this material to form an adherent film that is not removed by the casting alloy as it is being forced into the die is the one restricting factor in its use.

Natural or synthetic solid waxes such as beeswax, carnauba, and spermaceti cannot be used directly on die surfaces since they tend to build up deposits in corners and recesses. Emulsions of these waxes, however, are satisfactory. An emulsion of beeswax having the consistency of a thick cream works very well for the die surfaces in the die casting of zinc alloys, especially when a high surface finish is necessary on the casting. Copious use of this emulsion does not stain the casting or other-

wise affect the finish. However, such emulsions are not satisfactory for aluminum or the other higher melting point alloys, nor do they have sufficient lubricating properties for use on heavy slides, cores, and other moving parts.

Mineral oils of varying degrees of refinement have long been the most generally used die lubricants. They do not attack the die steel and are not readily oxidized. Mixtures of mineral oil with graphite or with colloidal graphite are widely used when casting high-temperature alloys and for the moving parts of dies and the shot cylinder of machines. A number of years ago when aluminum was die-cast at relatively low pressures, graphite suspended in mineral oil could be regularly applied to die surfaces and formed a good, adherent, shiny black film; however, with the advent of higher injection pressures and the attendant higher injection velocities, it became difficult, if not impossible, to form and maintain such a film when casting aluminum alloys. The chief disadvantage of graphite-oil mixtures is that if they are not properly or sparingly used, they tend to stain the casting badly.

Rules for Die Lubrication. Some precautions should be observed regarding die lubrication. These can be listed as follows:

1. Lubricants should generally be used as sparingly as possible. The excessive application of most lubricants may give rise to an undesirable surface finish and internal porosity in the castings. Yet it is necessary to have sufficient lubricant on all moving parts at all times to prevent galling and excessive wear. It should be remembered that the molten alloy entering the die decomposes oils and other organic matter. This causes the formation of moisture and gases which may not be readily disposed of through venting of the dies, and these gases may affect the casting soundness, especially when present in excessive quantities.

2. All kerosene, gasoline, and similar low-flash-point materials should not be used in die-casting dies.

3. Solvents, such as carbon tetrachloride and other similar chlorinated hydrocarbons that decompose with heat and form noxious products, should not be used on dies.

4. Lard oil and other similar animal and vegetable oils should not be used, or at least should be tested at elevated temperatures prior to use.

5. All ionizable salt solutions such as bromides and chlorides should be prohibited because they etch the die surfaces and cause surface corrosion of the castings.

6. Before any lubricant is adopted for use in any die, it should be subjected to laboratory tests to determine its effect on polished steel surfaces at elevated temperatures, as well as to determine its ability to meet all other requirements.

CHAPTER 4

DESIGN OF DIE CASTINGS

Two paramount considerations govern the design of die-cast parts, namely, *part quality* and *economy of production*.

If it is within the limits of size and weight imposed by commercial machines, almost any part can be die-cast. But if the commercial and mechanical advantages of the process are to be fully realized, each part must be specifically and carefully designed for die casting. To take a design originally intended for a sand casting, plaster-mold casting, or some other method of manufacture and apply it without appropriate changes to die casting is apt to result in unreasonably high cost, unnecessary complicated manufacturing problems, and impaired strength.

It is important to remember that the part will be cast in two halves of a die, that the die and cores will be made of solid metal, and that the part must be drawn out after the molten metal has solidified. Unlike sand castings, which are shaped by sand molds and cores that are destroyed after one part is made, die castings are formed by molds that must be used for large-quantity production. Thus, if the part is anchored by a projection or depression at an angle to the direction of removal, special—and costly—die construction must be resorted to, as will be discussed later in the chapter.

Parts of an assembly or assembled sections must be designed so that they occasionally can be separated. The designer should always consider the advisability of combining several or all of the components into one unit. Of course, there is a limit prescribed by the size and complexity of the combination. Sometimes the whole assembly can be taken care of with more than one die casting and still show marked savings in assembly and fitting cost. The possibility of casting in separately machined or otherwise fabricated parts, which are cheaper to produce by themselves than as part of the die casting and/or which locally impart specific properties not inherent in a die casting, is a powerful aid in making simplification of construction and over-all reduction of cost possible.

Even when all components of a rigid and permanent assembly cannot be combined, assembly of several die castings into the whole is made easier and less costly than is possible with most other methods of fabrication by providing integral fastening devices in the die casting, which

in assembly are riveted, staked, or spun over. This obviously is only feasible with highly ductile materials such as zinc and some of the aluminum and brass alloys.

SELECTION OF PARTING LINE AND GENERAL DESIGN

The first step of the designer in modifying or projecting a design for die casting is to select the parting line: the line on the part at which

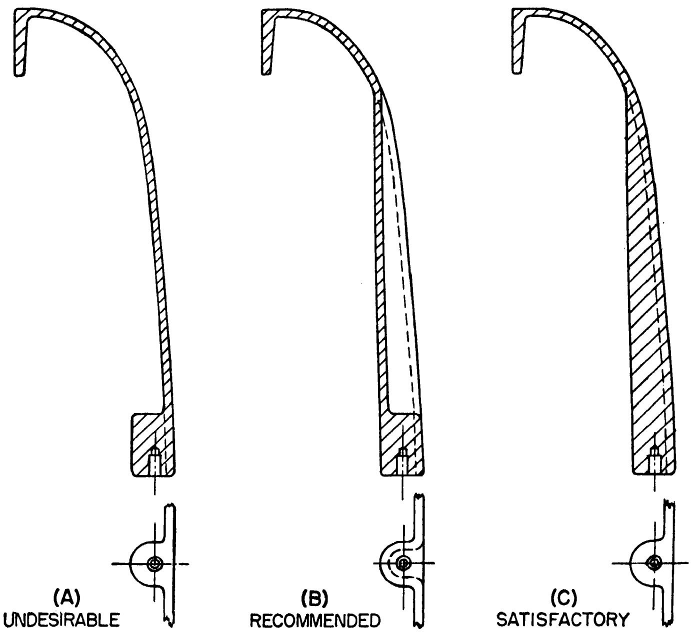


Fig. 4.1. Three designs for a die-cast part. That at *A* is undesirable because it is undercut and requires movable or loose die members to cast. That at *C* has no undercuts but requires more metal to cast. Neither of these disadvantages apply to the design shown at *B*.

the two halves of the die meet. Admittedly this usually is in the province of the die designer, but a knowledge of the end use of the casting is often essential when determining where the parting line should fall. The development engineer should always strive to modify the part design in order to provide for more speed and economy of production, with due consideration for the cost of trimming and finishing.

A flat or straight contour at the parting line is always preferable since the casting die is cheaper to construct, trimming dies are less expensive to build, and both types of dies are easier to maintain. This does not

mean that curved or irregular parting lines are not practical, but usually the matter is one of economics rather than of practicality of operation.

Actually, two primary factors govern the selection of the parting line:

1. Removal of the part on completion of the casting cycle.
2. The cost of constructing and maintaining casting and trimming dies and other cleaning equipment.

To these might be added other considerations such as efficiency of gating and venting; placement of ejector pins; and size, position, and type

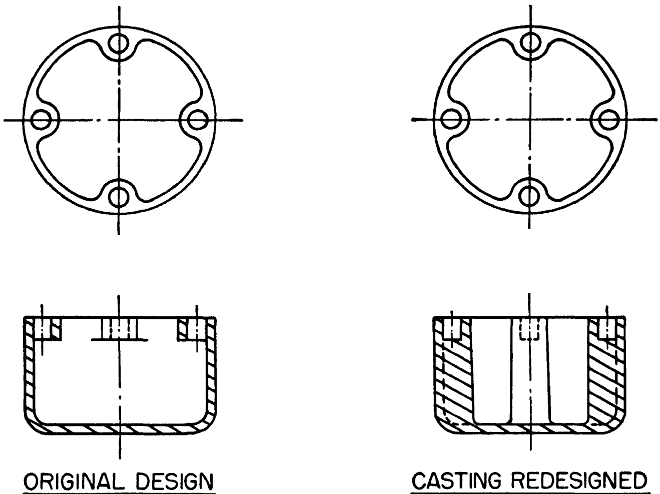


FIG. 4.2. Another example of how a casting was redesigned to simplify ejection on completion of the casting cycle. No undercuts are present in the redesigned part.

of cores required. Many of these are covered in detail in Chap. 2, Die-casting Dies.

As has previously been pointed out, the casting will be made in a rigid, inflexible die; therefore, the parting line must be selected so that the casting can be withdrawn after the shot is made. In general, the plane through the casting having the largest cross-sectional area should correspond to the parting plane. Failure to design the part with this in mind results in an undercut and usually necessitates costly die construction.

For example, the part shown at A, Fig. 4.1, is representative of a poor design. To cast it successfully would require either loose die pieces or an even more expensive collapsible core and operating mechanism. The design at C is better and can easily be produced, but it requires more metal to cast. The best design is that at B: it involves no undercuts, has a uniform wall thickness, does not have a large sectional bulk and can

be cored to permit the use of through bolts to fasten it during assembly.

A somewhat similar problem is illustrated in Fig. 4.2. The casting, as shown in the original design, would necessitate the use of loose die pieces to form the undercut presented by the four lugs. By continuing the lugs

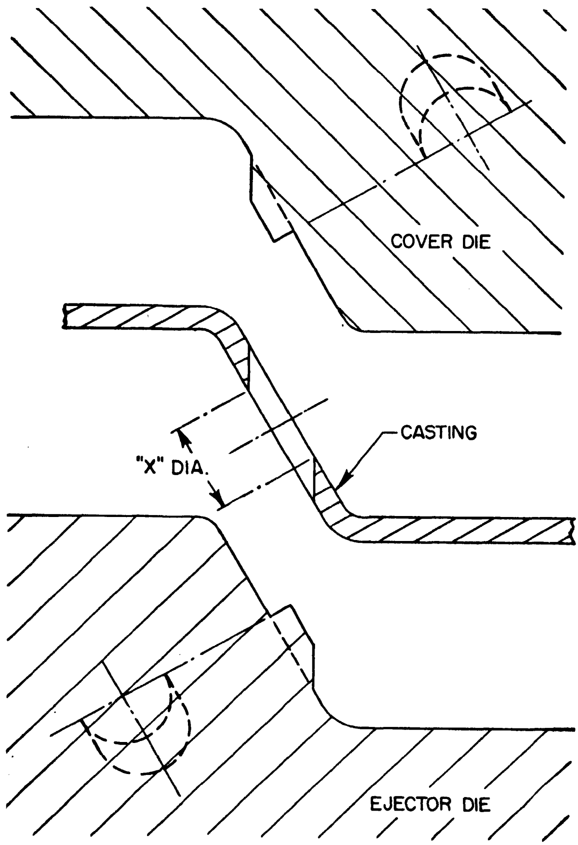


FIG. 4.3. How a round hole in an angular wall can be designed without an undercut. If the side walls are made parallel to the direction of die travel, the hole can be formed by the two halves of the die.

to the bottom of the recess, the undercut is eliminated. An even better design could be made if the bosses could be placed around the outside of the casting, thus not only eliminating undercuts, but accomplishing that aim without adding to the amount of metal required to cast the piece.

Equally simple solutions to the problem of undercuts are indicated in Figs. 4.3 and 4.4. A method of casting a round hole through an angular wall without benefit of a side core pull is illustrated in Fig. 4.3. The top

half of the hole is cast from the cover die; and the bottom half, from the ejector die. To accomplish this, however, the sides of the core must be relieved in relation to the draw of the die.

Illustrative of how another minor change can improve ejection from the die is the part shown in Fig. 4.4. In the design shown at *A* the two bosses and metal savers are at a 90-deg angle to the metal surface. However, the bosses and metal savers will be undercut in the casting die.

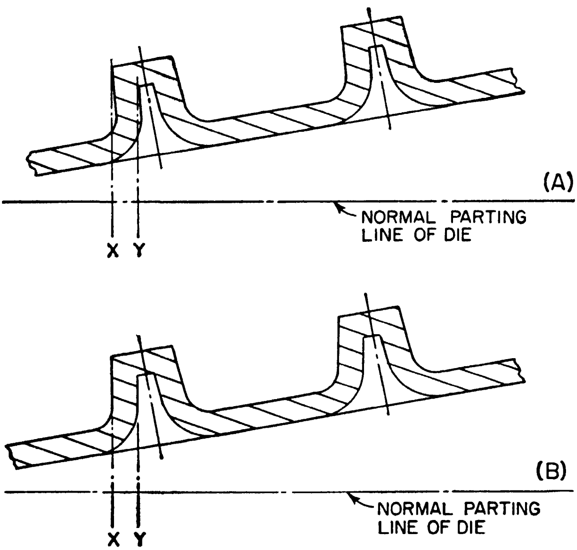


FIG. 4.4. The part shown at *A* will be undercut in the die by the angle between *X* and *Y* and the walls of the bosses. The undercut is eliminated at *B* by relieving the side walls to make them parallel to the direction of die travel.

Lines *X* and *Y*, drawn at 90 deg to the normal parting line of the die and projected through the boss and metal saver, indicate the undercut. By relieving one side of the boss and metal saver as indicated by lines *X* and *Y* at *B*, these undercuts are eliminated, and the piece can be cast without the necessity of expensive slides in the die.

Suppose, however, that the design of the part is such that the plane having the largest projected area cannot be made the parting line, that an undercut is necessary, or that simpler coring is possible if the parting line is specified at another location. In such cases, loose die pieces or collapsible or removable cores are required. For example, the part in Fig. 4.5 has an undercut that extends all around the casting. In this case, the undercut is formed by a round, main core that is stationary in the die, and by seven loose pieces. These loose pieces are located around

the main core and may be held in place by any of several means. After the shot has been made and the die opened, the casting and the loose pieces are ejected (as one unit) off the main core by means of ejector pins. The casting is then placed in a fixture and piece No. 1 is moved

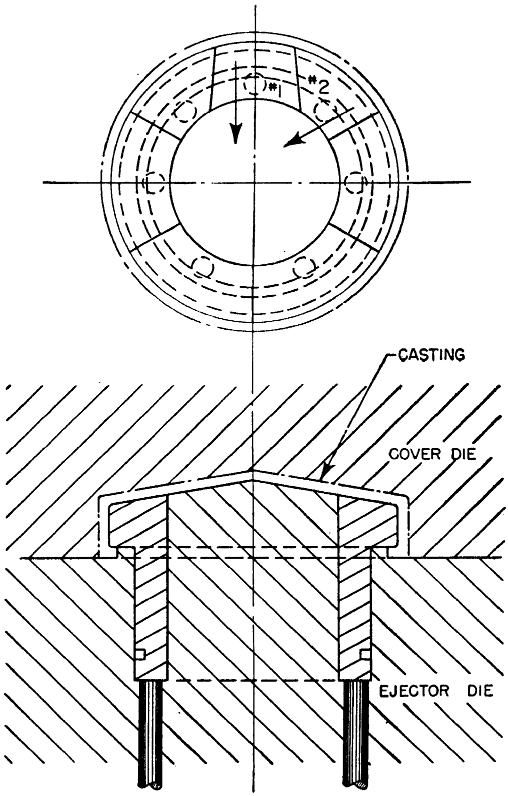


FIG. 4.5. One method of casting a part having an internal undercut that extends all around the casting. The undercut is formed by seven loose pieces that are assembled around the core prior to making the shot and are ejected with the casting on completion of the casting cycle.

into the center and withdrawn. The remainder of the pieces are removed in like manner. The loose pieces are then reassembled around the main core in the die and the process repeated. The flash, left in the casting at the split of the loose pieces, may be difficult to remove, depending upon the shape of the casting. This method of casting an undercut, although it may be the only way to obtain the undercut without machining it from the solid casting, is a rather slow and therefore expensive operation.

Another means of casting an undercut slot is shown in Fig. 4.6. A loose piece is placed in a slot in the die. A clearance is cut in the adjacent

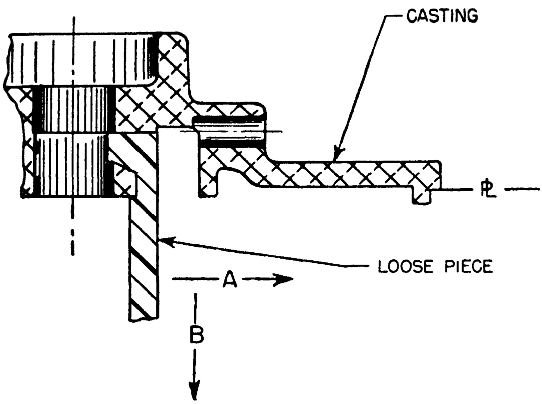


FIG. 4.6. Using a loose die piece that is ejected with the casting and removed from it by sliding the piece first in the direction of arrow *A*, and then in the direction of arrow *B*.

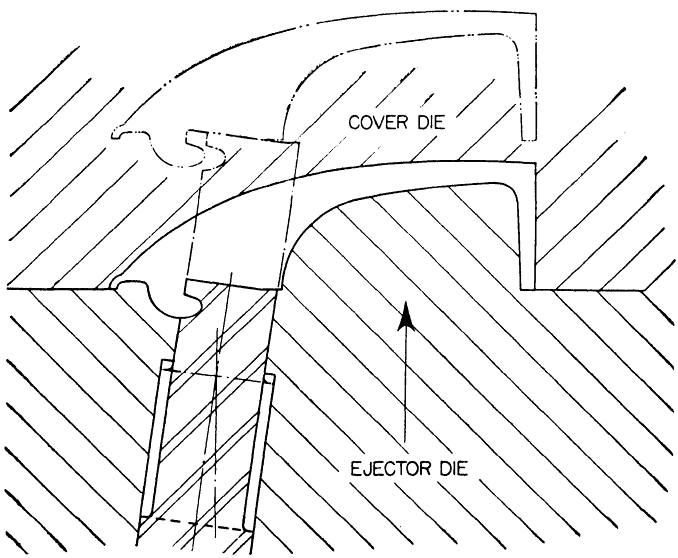


FIG. 4.7. The undercut in this part is formed by an angular die member that acts as both a core and an ejector pin. The part frees itself as it is ejected from the die.

core. The core from the opposite side of the die holds the loose piece in place while the shot is made. The loose piece is ejected with the casting, which is then placed in a fixture, where the loose piece is moved first in

the direction of arrow A and then withdrawn in the direction of arrow B.

In the die shown in Fig. 4.7, the undercut or hook is cut into a movable piece that is actuated by the ejector plate of the die. After the shot has been made and the die opened, the regular ejector pins eject the casting

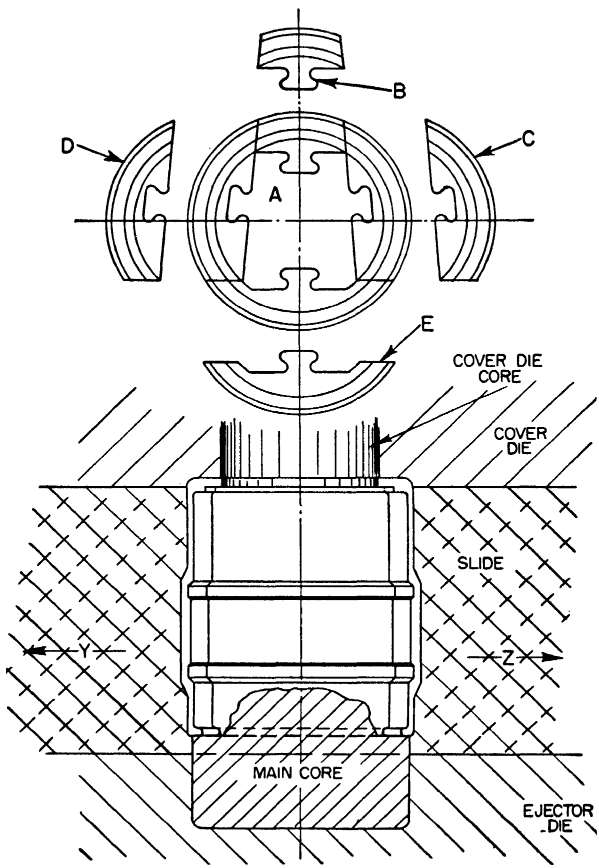


FIG. 4.8. The die members necessary to cast this part include a collapsible core, consisting of four main parts, and two side slides, Y and Z, that must be moved in the direction of the arrows prior to ejecting the part.

in the direction of the arrow. The piece, containing the undercut, moves with the ejector pins; but, since it is moving at an angle, it frees itself from the casting as the ejector movement continues. The loose die piece, in addition to casting the undercut, also serves as an ejector pin.

On many occasions it is necessary to use collapsible cores to cast undercuts. A typical example is shown in Fig. 4.8. The collapsible core is

shown in the top view as an assembled unit. This particular core consists of a main core *A* and four separate pieces, *B*, *C*, *D*, and *E*. The main core is fastened permanently in the ejector die. The loose pieces are assembled on the core prior to making the shot. After the pieces are assembled, the two opposing slides are run in, and the shot made. The two slides are then withdrawn in the direction of arrows *Y* and *Z*. The casting, along with the four loose pieces, is ejected off the main core. This unit is then placed in a fixture where the loose pieces are removed. Piece *B* is removed first, piece *C* second, piece *D* third, and finally, piece *E*.

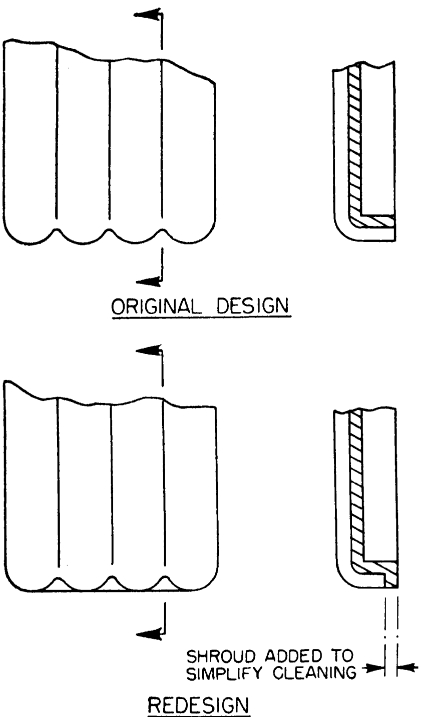


FIG. 4.9. By adding a shroud at the parting line of parts having complex contours, the trimming die is made less intricate, costly, and difficult to maintain.

The use of loose or movable cores to cast undercuts has two or three major disadvantages, not the least of which is the additional cost of the die; this, however, will be covered in more complete detail in Chap. 5, Comparison of Die Castings with Other Production Processes, so nothing more will be done here than to mention that this fact should be given considerable thought. The other disadvantages are that tolerances across loose die members cannot be held as close as across solid die sections, that casting speed is reduced, and that trimming and finishing are made more difficult due to the additional flash lines and seams on the casting.

As previously mentioned, trimming costs play an important role in the selection of the parting line. All die castings have at least a light flash at the parting line, around ejector pins, and around movable cores. Ordinarily, such flashes can be removed economically by shaving dies (especially when the flash comes at the parting line); by punches when the flash is across the end of a hole; or by broaching, grinding, or other cutting operations. When the flash occurs along a line that must be machined anyhow (as on a circular flange), it is removed during this machining operation. However, when gates and vents are on a flat part-

ing place around the edges of the casting, or when the flash occurs at some intermediate point on a surface rather than at its edge, a bead or a ridge added where the flash comes will make flash removal easier and less noticeable in the finished casting (Fig. 4.9).

The top view of Fig. 4.9 shows a casting having a scalloped edge. The trim die used in cleaning an edge of this type presents a serious maintenance problem, since the sharp corners of the scalloped edge in the trim-die steel are likely to break off. By adding a shroud to the casting at the parting line, as shown in the lower view, a straight edge is presented to the trim die, thereby lengthening the life of the trim die. If there is no trim die and the casting must be hand filed, the straight edge presented by the shroud can be filed considerably faster than if the workman must follow around the scallops.

Flash that occurs around the edge of a moving core pin is sometimes easily removed with a countersinking tool that leaves a slight chamber at the end of the hole.

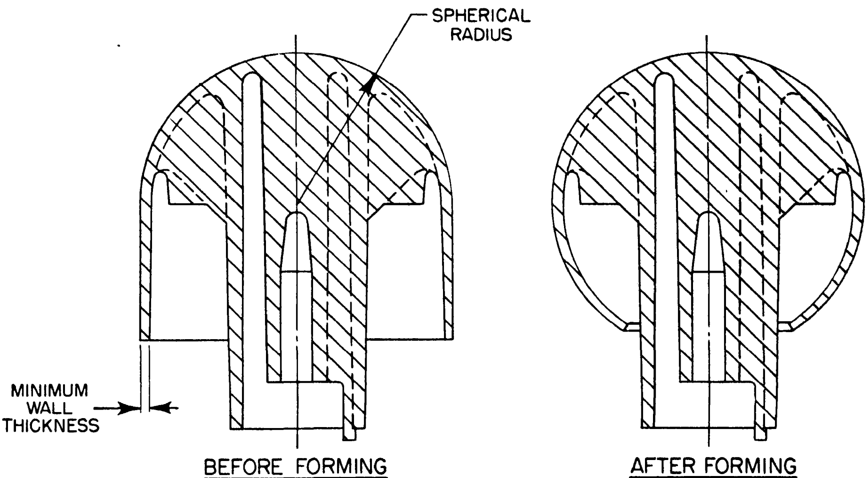


FIG. 4.10. Die-cast doorknob, before and after forming. Forming of high-ductility alloys after casting often makes possible the production of parts that would be difficult, if not impossible, to core.

FORMING AFTER CASTING

The designer can often contribute to lowering of the cost of a die casting by combining a forming operation with the die-casting process. For instance, a hollow section can be cast as a U, and after casting the edges can be rolled over to close the circle; this is shown in Fig. 4.10, which illustrates a method of casting a doorknob. The hub portion is cast

integral with a spherical shell, the skirt of which is carried down to a predetermined length. The casting is placed in a forming fixture and the skirt is rolled to continue the spherical shape. The casting is zinc alloy. The wall thickness, as noted, must be kept to a minimum. The wall stock in the knob illustrated was held to $\frac{5}{64}$ in. and was tapered to 0.050 in.

By another method, an impeller with cup-shaped paddles attached at various angles to the hub can be cast with all paddles in the same plane;

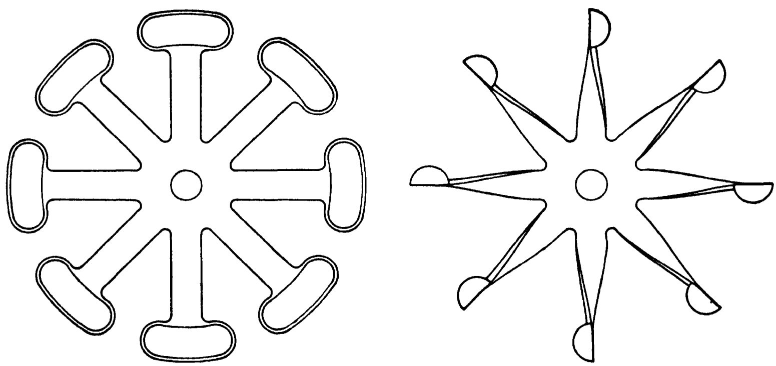


FIG. 4.11. Impeller with cup-shaped paddles that was cast in the flat and later formed to shape. This was an experimental casting made up to demonstrate the formability of zinc alloys.

after casting the paddles can be twisted into the required position, as illustrated in Fig. 4.11. Sometimes forming of the casting subsequent to casting not only reduces the die cost but also makes coring much less difficult. In general, such forming operations can best be done on the highly ductile zinc and brass alloys, but certain aluminum alloys are equally well adaptable, especially when slightly warm.

Another reference to forming is included in Chap. 9, Machining of Die Castings.

WALL THICKNESS

The thickness of a section depends upon various factors: the mechanical strength and stiffness requirements; the location of the section with regard to adjoining sections of different thickness; the fluidity of the alloy; and the general shape and size of the casting.

The ultimate object is to make the section as thin as possible, yet of great enough strength and stiffness and of sufficient thickness that rapid and complete filling of the die is not impeded by premature freezing in

the thin section. In general, a small casting of a shape promoting good casting conditions can be cast in thinner sections than larger castings; the lower melting point alloys—lead, tin, and zinc—can be cast in thinner sections than aluminum or magnesium, and aluminum and magnesium in thinner sections than the copper alloys, all conditions except the material being the same. Even in the aluminum alloys, however, there is quite a

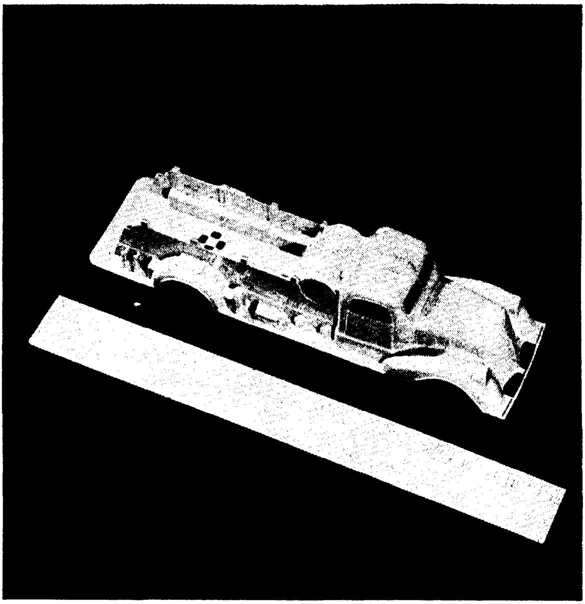


FIG. 4.12. Toy truck—a zinc die casting—has wall thickness of approximately 0.050 in., yet is sufficiently rugged to withstand abuse. Walls thinner than this are apt to cause freezing of the metal in the die.

difference. Under favorable casting conditions and for relatively small areas, the minimum thickness feasible is about 0.020 in. for zinc, 0.035 in. for aluminum, 0.050 in. for magnesium, and a little more for the copper alloys. Figures 4.12 and 4.13 illustrate two parts—one of aluminum and one of zinc—that are cast with walls which are close to the minimum thickness allowable in a die. In few applications, however, are the walls made so thin, for as thickness decreases, so does strength and load-carrying ability.

Because of the rapid chilling of the metal adjacent to the die walls and cores, and the temperature gradient extending from the outside of the casting toward the center of the section, heavy sections are likely to develop relatively larger grain and lower mechanical strength than thin

sections. Furthermore, internal porosity is greater in thick sections than in thin sections. The accumulation of metal in bosses and at intersections, therefore, should be avoided and, if possible, relieved by coring;

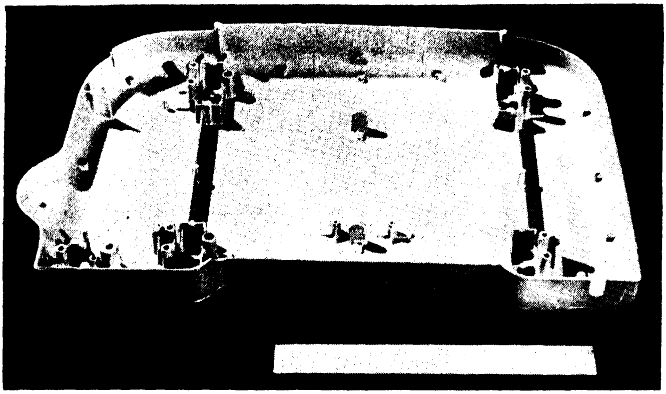


FIG. 4.13. Large zinc housing that was cast without difficulty even though wall thicknesses were close to the minimum. Seldom are large parts cast with walls so thin, for as thickness decreases, so does strength and load-carrying ability.

this is especially advantageous in heavy sections where drilling and tapping are required and where, without the core center, porosity may cause trouble.

FILLETS AND RADII

Since thin sections cool more rapidly than heavier ones and unrestricted contraction is not feasible with unyielding metal dies and cores, shrinkage stresses are apt to occur where sections of unequal thickness

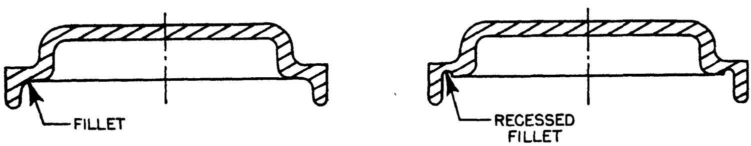


FIG. 4.14. When sharp corners are required for purposes of assembly, use of a recessed fillet obviates shrinkage stresses and possible breakage that might result were the edge made sharp.

meet. Where possible, metal thickness should be uniform throughout the casting. At the juncture of unequal sections, the transition should be gradual and fillets should be provided. The radius of these fillets may be quite small if the casting does not need to resist any stresses; generally,

however, it should be as near the arithmetical mean of the two sections as possible.

Fillets are also desirable in corners, even where two equal sections meet, to avoid stress concentration. When sharp corners between sections meeting at right angles are demanded for reason of mating with other sharply cornered parts in assembly, and when the corners of the mating part cannot be rounded off or chamfered, the shrinkage stresses may be obviated by a recess below the level of the heavier section, as shown in Fig. 4.14.

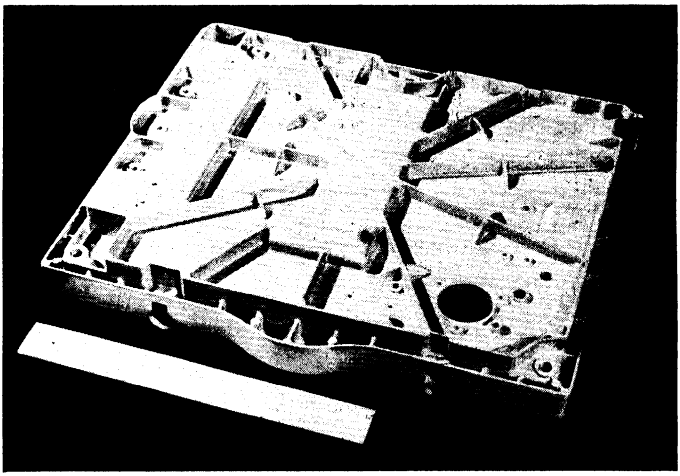


FIG. 4.15. Base for a mechanical scale cast of S9 aluminum alloy. Note the well-rounded edges, liberal fillets, and large radii used at all intersections. Dies for such parts are easier to machine and part breakage is less than if the corners were sharp.

Other points at which fillets and radii promote stronger sections, improve die life, and make easier subsequent polishing or finishing operations are

1. At the edges and corners of a casting, as illustrated in Fig. 4.15.
2. At the bottom of a blind hole; at the bottom of grooves; and at the edges of projections, fins, and lettering.
3. At the junction of any projections with the main casting body.

Fillets are especially desirable on the corners of dies that are to be used for high-melting-point alloys: aluminum and copper. Molten metal enters the dies under high pressure and tends to erode and cause checking of the die at points where the flow changes sharply in direction. On dies

for zinc, the condition still exists, but to a lesser degree because of the better die materials available for these alloys.

As previously pointed out, there is one place where a sharp edge is often desirable: on the parting line between two die halves. There, the existence of a radius or fillet might necessitate feather edges on the die or add considerably to the cost of the trimming die.

TOLERANCES

Tolerances, *i.e.*, the permissible variation of certain dimensions of the casting from the dimensions stated on the drawing, should be governed only by the requirements of assembly and operation. The closer the tolerance, the higher the cost of the die, and the more the interference with smooth and uninterrupted production. Even though it is possible to obtain close dimensional tolerances, the designer should always prescribe them as liberally as feasible under the prevailing conditions.

Minimum and commercial tolerances that can be held in the solid part of the die are as follows. It should be remembered that even the commercial tolerances may be difficult to hold on some parts, depending upon part size and complexity, and should be increased whenever possible.

Alloy	Minimum tolerance, in.	Commercial tolerance, in.
Zinc	±0.001	At least ±0.0025
Aluminum	±0.0015	At least ±0.003
Copper	±0.003	At least ±0.005
Magnesium	±0.0015	At least ±0.003

At least 0.010 in. should be added to any dimension extending across moving parts of the die, such as across the parting line of the die or between a point in the die block and a core or insert. Table 4.1 gives commercial tolerances for cored holes and bosses.

A so-called "flatness tolerance" is sometimes given as equal to the largest dimension of a flat surface multiplied by 0.0015 (Aluminum Company of America designation for Alcoa die castings). For instance, a rectangular surface 6 by 12 in. would have a diagonal of approximately 13½ in., and the flatness tolerance would be $13\frac{1}{2} \times 0.0015 = 0.020$ in. However, especially in thin-walled castings, maintenance of this tolerance may sometimes require the casting to be straightened after having been distorted in handling.

TABLE 4.1. LIMITS FOR DESIGN OF DIE CASTINGS *

Casting detail	Die-casting alloy					
	Zinc	Aluminum	Magnesium	Tin	Lead	Copper
Maximum weight of casting, lb	35	20	10	10	15	5
Minimum wall thickness, large castings, in.	0.05	0.08	0.08	1/16	1/16	1/8
Minimum wall thickness, small castings, in.	0.015	0.035	0.035	1/32	1/32	0.050
Shrinkage per inch of diameter or length, in.	0.001 †	0.0015 †	0.0015 †	0.001 †	0.001 †	0.002 †
Maximum number of cast threads per inch:						
External	24	20	16 to 20	32	32	10
Internal	24	None	None	32	32	None
Minimum draft, in. per in. of length or diameter:						
On cores ‡	0.003	0.010	0.010	None	None	0.020
On side walls	0.005	0.010	0.010	0.005	0.005	0.020
Minimum diameter of cast holes, in.	0.031	3/32	3/32	0.031	0.031	1/8

* Data are for average conditions. A considerable range for all data can be obtained by special design techniques. This is especially true for casting weight and wall thickness.

† Depends to a large extent upon design details and casting conditions.

‡ Depends somewhat upon length of core.

CORED HOLES AND RECESSES

One of the main advantages of the die-casting process—which is not possessed by many other casting processes—is that intricate coring of holes, slots, and recesses can be quite easily accomplished if the additional cost of the die is to be amortized over a large number of parts. In fact, while movable, collapsible, intersecting, or racking cores often are derided as expensive additions to the die, they may be the means that justify producing the part by the die-casting process.

The parts illustrated in Fig. 4.16 prove the point. These are die-cast aluminum parts for the General Motors Hydra-Matic transmission. The holes and recesses at right angles to the parting line are necessary, since they carry fluid to and from the cored recesses in the face of the part. It is difficult to imagine how such parts could be machined on a production basis—or sand-cast, forged, or made by any method other than die casting. Certainly, intricate coring is justified in this case.

Similarly, the part shown in Fig. 4.17 also justifies the use of intricate coring mechanisms. It is a magnesium harness housing for an aircraft-engine ignition system. Without the use of retractable cores, the piece would have been impossible to produce.

Nevertheless, it still is worth emphasizing that complex coring mechanisms add to die cost and increase the cycle time on the casting. The interlocking cores shown in Fig. 4.18, for example, must be withdrawn

from the casting by means of mechanical or hydraulic core pulls, incorporated in the die. The cores illustrated are located in the cover half of the die, and, while core *A* projects through blades located in both the

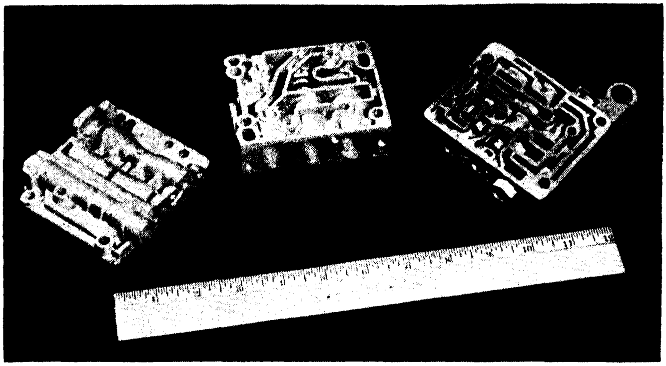


FIG. 4.16. Die-cast aluminum housings for an automatic automobile transmission. The fact that parts requiring such intricate coring can be produced—even though dies are relatively expensive—is one of the advantages of the die-casting process.

cover and the ejector dies, core *B* casts through only to the first blade. Core *A* must be withdrawn in order to open the die, and core *B* must be withdrawn to keep the casting from staying in the cover die. Both cores, therefore, must be withdrawn before the die is opened. Therein lies an-

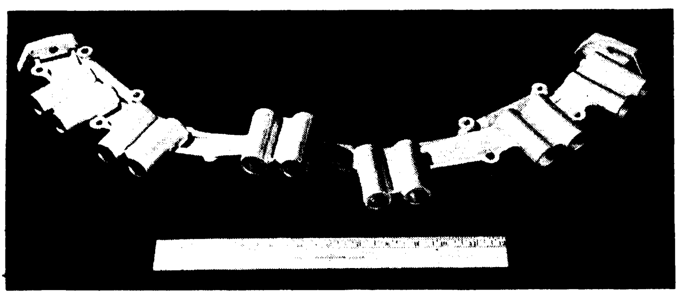


FIG. 4.17. Use of angular, sliding cores was justified for the production of this part because it could economically be made by no other method. It is an aircraft ignition harness housing cast of magnesium.

other disadvantage of interlocking cores: the danger of opening the die before the cores are withdrawn, thereby breaking the blades and damaging the cores.

Another fact that should be remembered is that, since metal enters the die under high pressure and at high velocity, a slender core of considerable

length should be avoided. Table 4.2 gives some general data on the permissible length of cores as governed by material and diameter of the

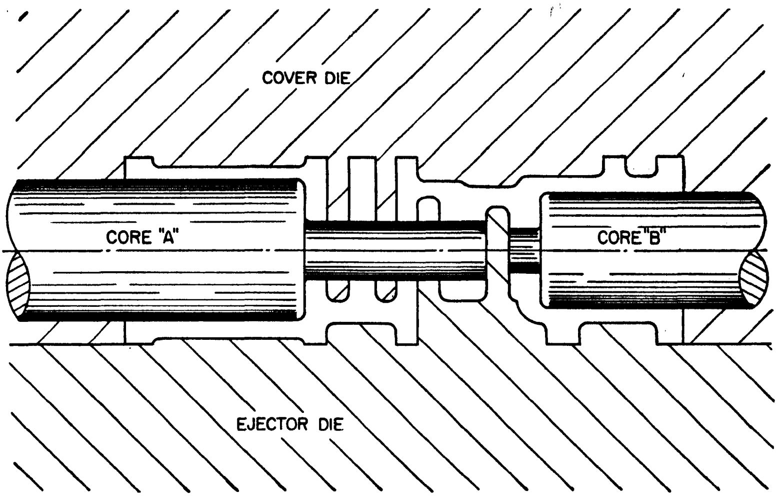


FIG. 4.18. Interlocking cores, which must be slid out along their center line before the die can be opened. Although sometimes necessary, such cores slow up the casting cycle and are subject to breakage if the die is opened before they are withdrawn.

core. When deeper holes than shown are required, it may be advisable to core part of the depth and drill the rest.

TABLE 4.2. MAXIMUM DEPTH OF CORED HOLES

Alloys	Diameter, in.	Maximum depth in relation to diameter
Magnesium	Smaller than 0.093	Not cored
	0.093 to 0.250	3 times diameter
	0.250 to 1.000	3 to 5 times diameter
Aluminum	Smaller than 0.093	Not cored
	0.093 to 0.250	3 times diameter
	0.250 to 1.000	3 to 5 times diameter
Zinc	Smaller than 0.093	Not generally cored
	0.093 to 0.250	3 to 8 times diameter
	0.250 to 1.000	6 to 8 times diameter
Copper (brass)	Smaller than 0.186	Not cored
	0.186 to 0.500	1½ to 3 times diameter
	0.500 to 1.000	3 to 5 times diameter

DRAFT FOR WALLS AND HOLES

When molten metal solidifies, it shrinks away from die walls inside the die and around cores and die sections projecting into the casting. *Draft* is the taper given to these sections to facilitate removal of the casting from the die. It must be greater for the die sections that the metal shrinks around than it is for those that the metal shrinks away from. It also must be more for the metals of higher solidification shrinkage, which generally means the metals having the higher melting points.

The designer, as a rule, is not directly interested in the amount of the draft used by the die caster unless the draft interferes with assembly with mating parts. In such cases the drawing should state the maximum permissible draft and its direction. Otherwise an additional machining operation may be required. Minimum drafts for cored holes and walls in inches per inch of depth of draw are given in Table 4.1. Tapers for cast sections shrinking away from the die may be less. As with tolerances, however, it is not advisable to call for the lowest permissible draft, since the withdrawal of the casting from the die and cores without tearing, sticking, and distortion is made easier with liberal drafts.

INSERTS

Inserts are separately fabricated parts that are cast in and become an integral part of the casting. There are several important and necessary reasons for using them:

1. To provide means for joining the die casting to other mating parts during assembly. They thus obviate the necessity of bolting, pinning, screwing, or welding individual pieces to the casting after it comes from the casting machine. For example, studs are often used as inserts. These studs may be threaded, if required, or speed nuts may be pressed over them during the assembly operation.
2. To impart to the die casting certain properties that are not inherent in the cast metal. Examples are inserts used for additional mechanical strength, hardness, corrosion resistance, arc and spark resistance, spring resiliency, magnetism, or as a base for soldering. Some typical applications of this sort are illustrated in Figs. 4.19 to 4.22.

The die-cast hub (Fig. 4.19) is used to transfer power. For purposes of wear and strength, a hardened steel or bronze insert is cast in place and secured against both radial and end thrust by means of the four lugs located around the outside of the insert. In casting, the insert is placed over a splined core in the die. The designer must bear in mind that on

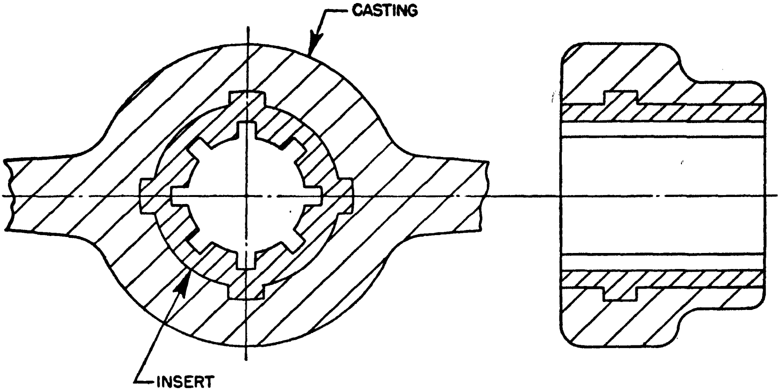


FIG. 4.19. A hardened steel spline is "cast in" this hob to impart to it additional strength and wear resistance. The insert is locked in place by four projecting lugs.

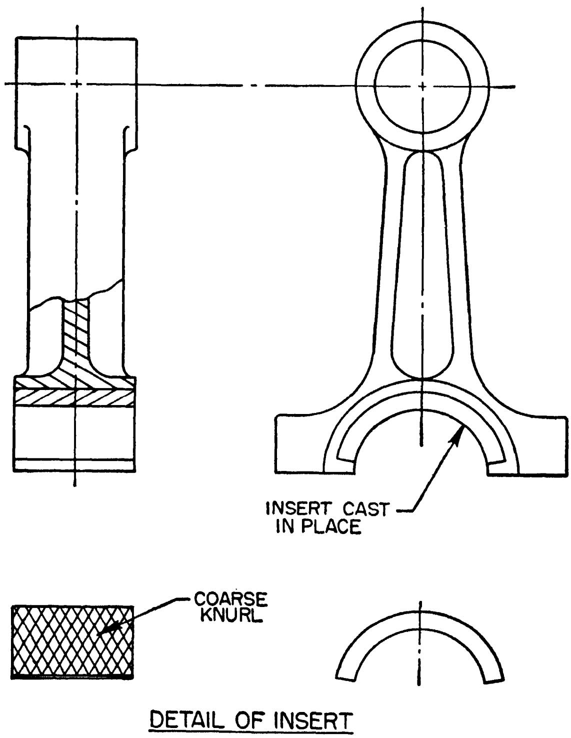


FIG. 4.20. Aluminum connecting rod with bronze bearing cast in place. The insert is secured against radial and axial thrust by metal cast over the ends and by the coarse knurl on its outer surface.

applications of this sort a slight flash may form over the end of the insert and may also work down into the grooves of the insert, resulting in the necessity for additional machining and broaching operations.

Another application in the same category is shown in Fig. 4.20. The part is an aluminum connecting rod with a bronze bearing cast in place.

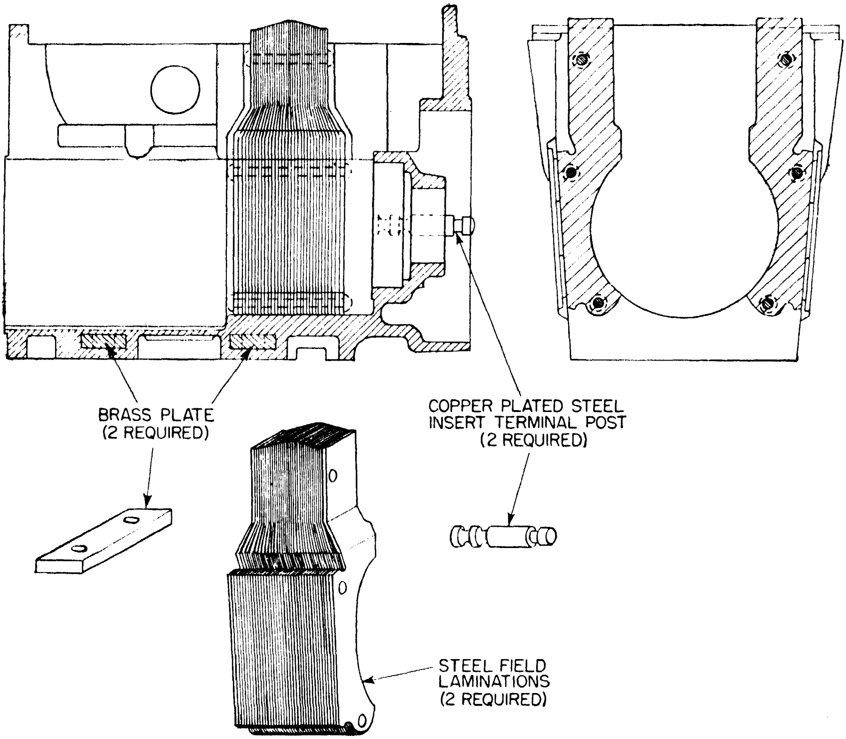


FIG. 4.21. Steel laminations often are used as inserts to impart magnetic properties to castings to be used in electrical applications. The shape of such inserts locks them securely in position.

As noted, the insert is secured against radial thrust by metal cast over both ends. The insert is further secured against both radial and end thrust by means of a coarse diamond knurl. A round, knurled insert (not shown) could be cast in the top hole, if desired. The reader will also note that the center section of the casting has been cored out to leave a uniform wall stock. This H section will effect a considerable savings to the customer in weight, and will result in a stronger casting due to the elimination of porosity and blow holes.

An example of the use of inserts to impart magnetism to a nonmag-

netic aluminum casting is shown in Fig. 4.21. In this case, two stacks of steel field laminations are cast in; their function being to create a mag-

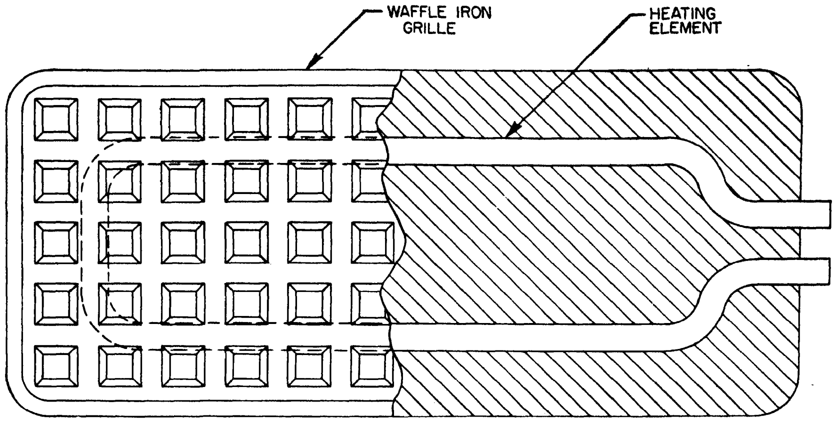


FIG. 4.22. Sketch of an aluminum waffle grill having Calrod heating element inserted in the casting.

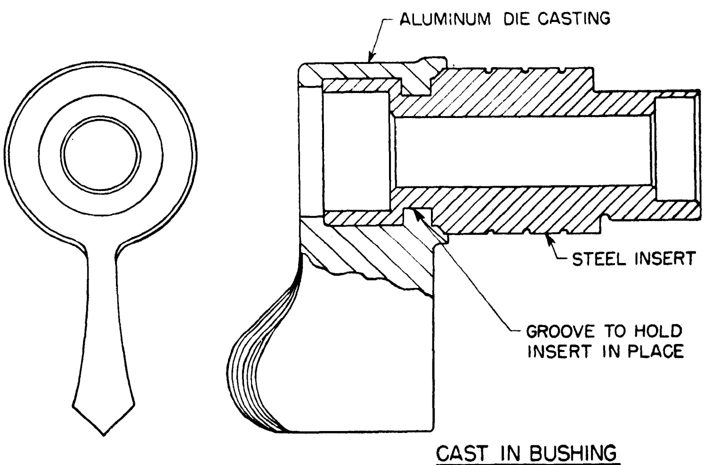


FIG. 4.23. Lugs were used as inserts in the die-cast aluminum hub for a fan, shown here, to facilitate later assembly operations. A stamped steel outer ring is later fastened in place, with the lugs being used as rivets.

netic field, it is not necessary to insulate them from the casting. Rotors for fractional-horsepower motors also are usually die-cast with steel laminations being used as inserts.

Finally, the use of inserts as heating elements is shown in Fig. 4.22.

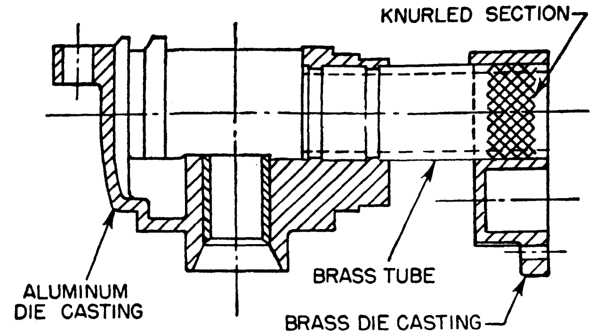


FIG. 4.24. Brass and aluminum die-cast assembly. First the brass section is cast with a tubular brass insert; then the other end of the tube is cast in with the aluminum section. The part is an outboard-motor gear-case head.

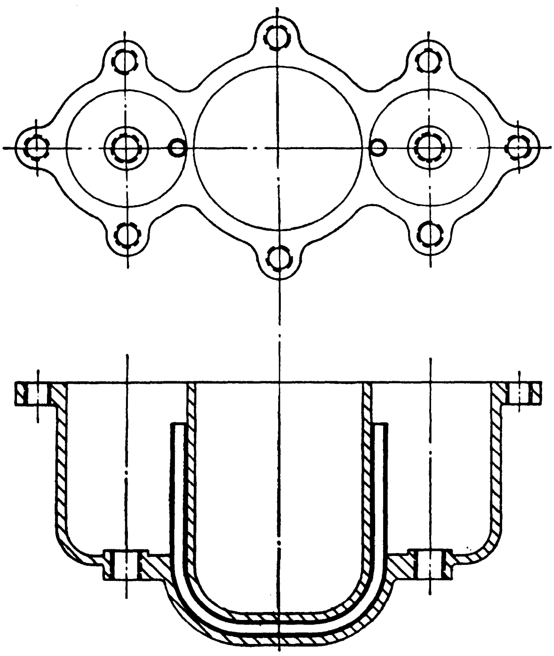


FIG. 4.25. Tubular inserts often are used to form curved holes, as shown here, thus making racking cores or other expensive die devices unnecessary.

The unit is a die-cast aluminum-alloy waffle grid with the Calrod heating element cast in place. In this and other appliances, such Calrod inserts are held securely in place by their shape.

3. The third and last use of inserts is to take the place of intricate coring, to eliminate undercuts, and to simplify the casting and reduce die cost by replacing certain complicated sections of the casting by parts fabricated independently. For example, the sketch shown in Fig. 4.23

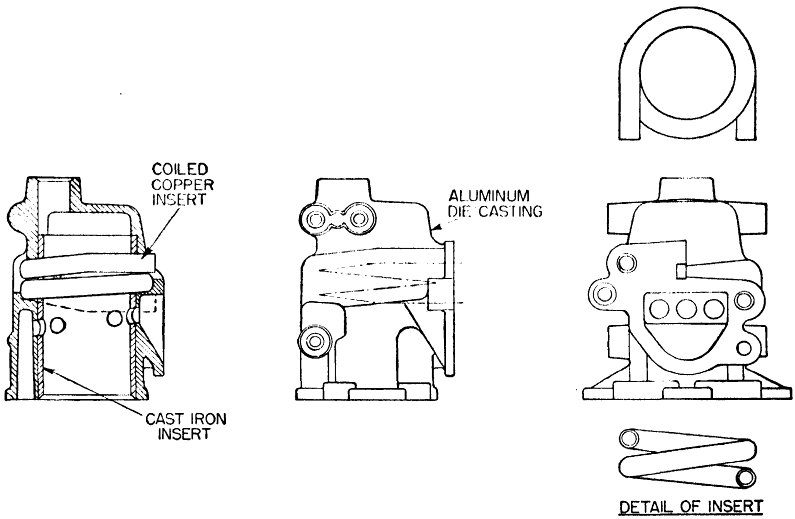


FIG. 4.26. Design of the die for this aluminum cylinder for an outboard boat motor is simplified by use of a coiled copper insert. The insert forms a circular cooling passage that would be impossible to core.

illustrates an assembly composed of an aluminum-alloy casting and a steel bushing that was previously machined to shape. Note that the insert is held in the casting by a groove, which is easily turned into the part during the machining operation. If the entire assembly were to be made as a one-piece casting, the die and cleaning cost would be exorbitant.

A somewhat different design with an insert being used to join two die-cast parts in an assembly is shown in Fig. 4.24. In this assembly, which is a gear-case head, a tubular brass part is held securely in a brass die casting by knurling. These parts form a second insert that is cast in an aluminum body and is secured by two grooves in the original brass tube. Obviously, the aluminum and brass pieces forming this assembly could not have been cast at the same time.

In Fig. 4.25 is pictured a section of a die casting which illustrates how a curved hole may be cast. In this instance, a brass or copper tube is

used to form the hole. The tube is preformed to the U shape and in casting is located in the die by slipping the ends onto two short cores, which are turned to a press fit with the inside diameter of the tube. The die-cast metal, either zinc or aluminum alloy, is then cast around the tubing and the whole assembly removed from the die.

Another similar casting, cored with an insert to provide a cooling passage for the cylinder of an outboard motor, is shown in Fig. 4.26. This coil also serves another purpose, namely, to prevent the seepage of water into the cylinder head.

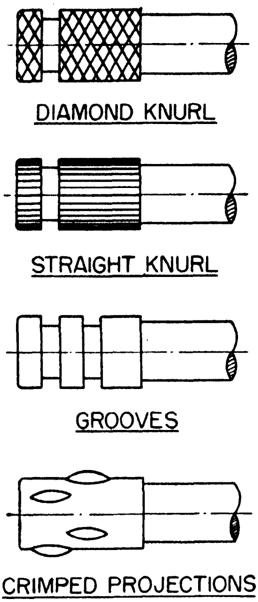


FIG. 4.27. Four common methods of locking inserts in die-cast parts. Sometimes the shape of the insert will hold it securely in position.

Designing of Inserts. As indicated by the foregoing sketches and by Fig. 4.27, there are several methods of preparing such inserts so that they become firmly anchored in the casting. Of course, the designer should realize that as a rule there is no fused or welded bond between the insert and the cast metal and that the rigidity of the joint depends upon the mechanical locking features. Although knurling, grooving, and crimping are, perhaps, the most frequently used locking methods, holes also can be used to anchor inserts; however, the holes must be large enough to let metal pass through so that the insert is pinned to the casting.

Threaded studs cast in as inserts are preferably provided with a step or shoulder located slightly above (outside) the surface from which the stud projects. This not only helps to prevent metal from flowing into the thread but also helps to prevent the stud from coming out by excessive tightening of the nut, since the shoulder takes the pressure and keeps the stress within the stud itself. Care should be taken to provide enough cast metal around the insert to ensure sufficient support.

All kinds of material may be used for inserts, ranging from paper, wood, plastics, insulated wire, and porous metals to spring and tool steels. The insert may be a casting, screw-machine part, stamping, punching, forging, strip, tubing, bar, rod, or almost any other form. Low-burning-point materials like paper and wood are restricted to the lower melting point die-casting alloys like lead, tin, and zinc to prevent charring.

Dissimilar metals used as inserts in commercial die castings of lead, tin, zinc, magnesium, aluminum, and copper may cause electrolytic corrosion when the finished part is exposed to moisture and humidity. Especially is this so when the volume of the die-cast metal surrounding the insert is considerably smaller than the insert and when the insert metal is cathodic to the die-casting alloy—cuprous compositions, nickel and nickel alloys, or stainless and rustless steels used as inserts in aluminum and magnesium castings. In such cases the joint between the insert and casting should be adequately protected against the entrance of moisture (unless a continuous coating of lubricating oil is present, as in bearings) to prevent electrolytic corrosion from attacking the anodic material and possibly weakening the tightness of the joint. In the case of zinc die castings, another factor must be considered: the effect of tin that has been cadmium coated before being cast in.

For magnesium, plated-steel inserts are preferred to brass, bronze, or other nonferrous metals because there is less danger of an alloying action when the magnesium is cast around them. If nonferrous inserts are used they should be chromium plated or sprayed with iron. Steel inserts will not contaminate scrap as will nonferrous inserts when castings are remelted, a fact to be taken into consideration by the die caster when pricing the casting and also by the consumer when disposing of his scrap.

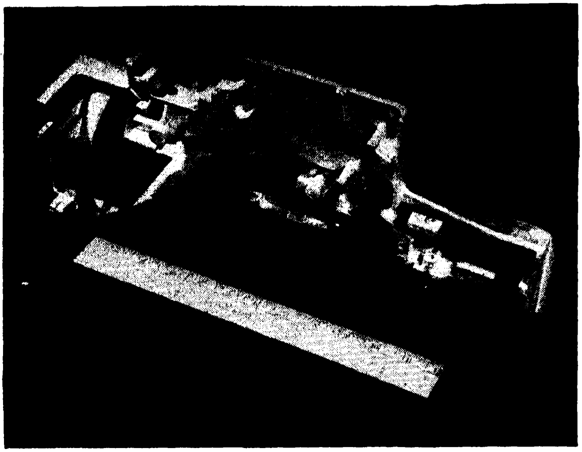
Inserts are apt to interfere with the normal shrinkage of the die casting and to cause distortion. They should therefore not extend too far into the casting. Furthermore, it is advisable in the design of inserts to avoid sharp corners, projections surrounded by thin sections of cast metal, and other factors that might lead to stress concentration. And lastly, the designer should remember that inserts cannot be located so accurately as a cast member—an important and often overlooked factor to be considered when establishing tolerances.

BOSSES AND PROJECTIONS

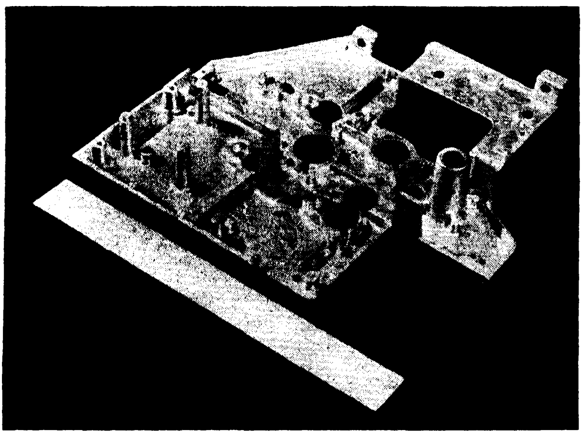
Bosses are used primarily as fastening points or bearing points when a die casting is later to be fitted to mating parts or is to serve as a housing or frame for mating components. The use of bosses and projections for such purposes is graphically illustrated by the castings shown in Fig. 4.28.

Bosses may be needed in a casting for other reasons, however: to act as spacers, to increase strength and stiffness of the part, to serve as ejection or as gating or venting points for the casting, to act as locating points

for subsequent machining or trimming operations, or, in some cases, simply to equalize stresses and prevent distortion opposite heavy sections of intricate castings.



a



b

FIG. 4.28. These two die-cast aluminum parts graphically show the importance of bosses and projections for bearing surfaces, fastening points, and strengthening purposes. The casting at *a* is a side frame and motor housing for an electric typewriter, while that at *b* is the side frame for a business machine.

An often-used "trick" in die-casting small parts that are to be later fastened to another surface is to cast on studs that can be threaded or fastened with speed nuts. As a matter of fact, such practice is more economical than using threaded inserts if the metal is soft enough so that

speed nuts can be used; if the studs must later be threaded in a die, however, inserts may prove to be more practical. Name plates, such as shown in Fig. 4.29, are usually designed with such projections or studs.

Whatever the use, bosses and projections should be provided with generous fillets to prevent stress concentrations at the points where

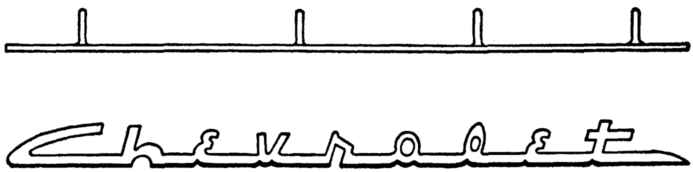


FIG. 4.29. Name plate with cast-on projections that later are utilized as studs when fastening the plate to the automobile. Speed nuts eliminate threading the projections with a die.

they are joined to the main casting body. If they represent relatively large concentrations of metal or project a considerable distance from the body of the casting, they should be reinforced with ribs. Cylindrical or tubular cavities are perhaps the easiest to machine in a die block, and such shapes are therefore recommended for bosses and projections when the function they are to serve does not dictate otherwise. Irregular projections, especially those that are deep and narrow, add to die cost.

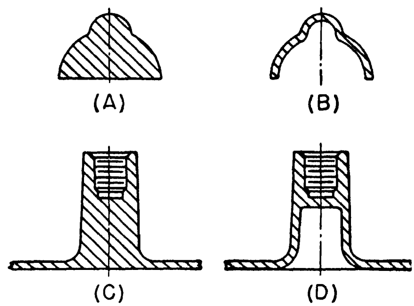


FIG. 4.30. Metal savers—cores that extend part way through projections, bosses, and heavy sections—not only decrease the weight but minimize porosity. They should be considered whenever heavy sections must be cast.

All metal concentrations, of course, are potential focal points for stresses and porosity. If through necessity, therefore, a boss or projection must be heavy, inserts can be placed in their centers to chill the surrounding metal, thus reducing porosity. Another practice that is highly recommended is the use of "metal savers," which are cores on the other side of the casting that extend part way up through the projection. Typical sections through two castings before and after adding metal savers are shown in Fig. 4.30.

The advantages, both to the manufacturer and to the customer, of adding these metal savers is worth reiterating. Castings with heavy metal sections are difficult to cast, must be adequately water-cooled to

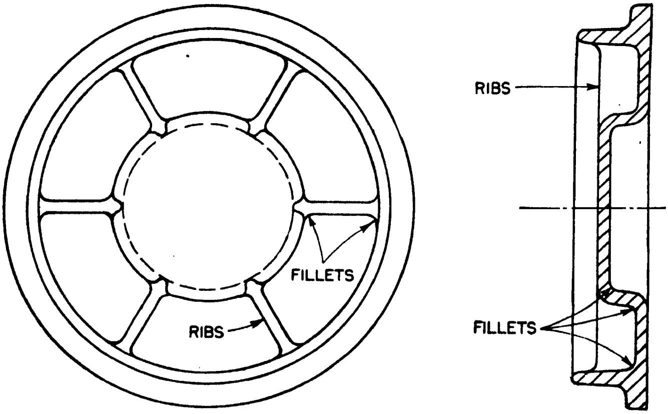


FIG. 4.31. Ribs and generous radii—⅛ to ¼ in.—add to the strength and stiffness of die-cast parts, often eliminating distortion that might occur when the part cools and is ejected.

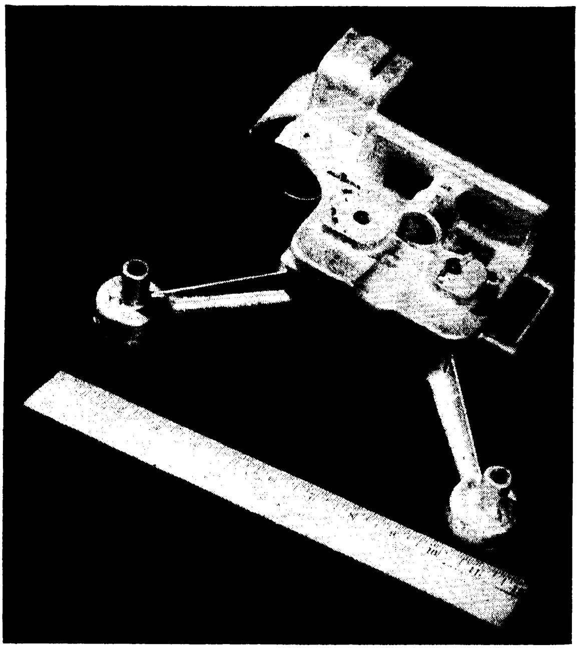


FIG. 4.32. On heavy bosses and overhanging projections, ribs add stiffness and act as feeders in filling such sections in the die. Without ribbing, the arms on this casting (a housing for an 8-mm motion-picture projector) would be bent and eventually broken in service.

prevent the casting from blowing up, and generally result in slower production. Thin wall sections provide a better exterior finish and a sounder metal structure due to the elimination of excessive porosity and blowholes, which are the result of heat and trapped air. In *D* there is an additional advantage in that a better tapped hole will be obtained due to the absence of porosity and blowholes.

RIBS AND FINS

Ribs are used to a large extent in die castings, principally to increase strength and stiffness, to decrease warpage, and to facilitate the flow of molten metal into the die cavities during the casting cycle.

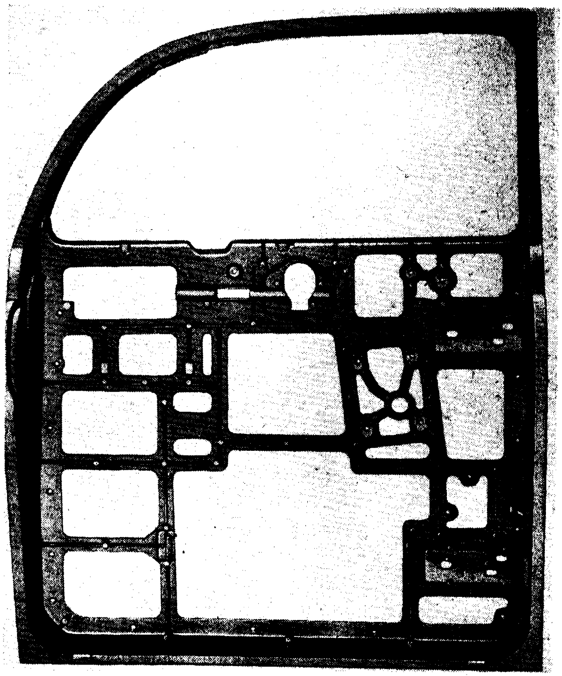


FIG. 4.33. Experimental aluminum door frame for the Kaiser automobile. Ribbing greatly stiffens the door and increases its resistance to impact.

A heavy-walled casting may be lightened considerably and at the same time greatly strengthened by decreasing the wall thickness and adding ribs. Also, it is usually advantageous to add ribs to deep bosses or heavy metal sections, tying such sections to the main body of the casting as illustrated in Figs. 4.31 and 4.32. The ribs then act as gates or feeders and aid materially in filling these sections in the die.

Large flat areas often are ribbed to minimize distortion when the part cools. In this case, shadow marks may form opposite the rib on the other side of the casting. To eliminate this effect, two rows of shallow beading or ribbing may be added on that side of the part. Such beading will mask the marking and greatly improve the surface appearance.

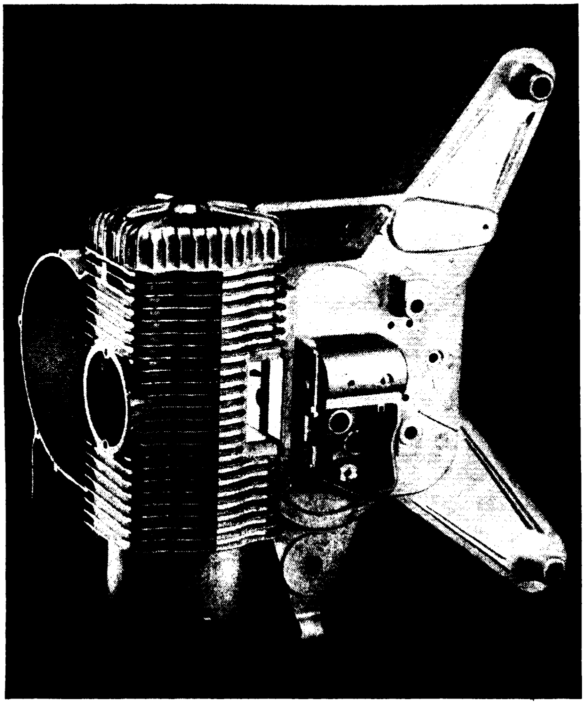


FIG. 4.34. Ribs often are used as cooling fins on cylinder heads for engines and compressors, and on housings for motion-picture projectors, such as shown here.

Perhaps one of the most effective uses of ribs for strengthening purposes and for aiding in metal flow is in the die-cast aluminum automotive door frame (Fig. 4.33). This casting, which is believed to be the largest part ever die-cast of aluminum, is approximately 43 in. high and 33 in. wide. Even casual examination reveals that the inner sections must be braced for stiffness and that adequate passage must be provided for the metal to reach all sections of the casting before it starts to solidify. With no ribbing, this frame would be impossible to cast and eject without distortion.

Ribs also can be used as cooling fins on such parts as motion-picture projectors, cylinder walls and heads of compressors, and similar equip-

ment (Fig. 4.34). Often the rib also serves to strengthen the casting. Design and spacing of such ribs or fins is almost entirely a function of the cooling requirements. A distance of $^{11}/_{32}$ in. or greater between centers is a fairly safe allowance in so far as practical commercial die casting is concerned. Even so, a die for this type of part is hard to cool and may burn off where it projects between the fins. Frequent lubrication of the die is necessary to prevent "spongy" areas being formed between the fins.

When fins (or ribs) must be closely spaced, the shrinkage of the metal on cooling may cause the part to adhere to the die and thus cause problems in ejection. For this reason, a draft usually is provided on the fins at least equal to that required for inner walls and cored holes and often is increased to several times the allowable minimum. Also, all fins, bosses, and other projections should if possible be in the ejector half of the die, for otherwise the casting may stick to the cover half of the die or to both the ejector and cover half, thus causing warpage or breakage of the part and possible damage to the die.

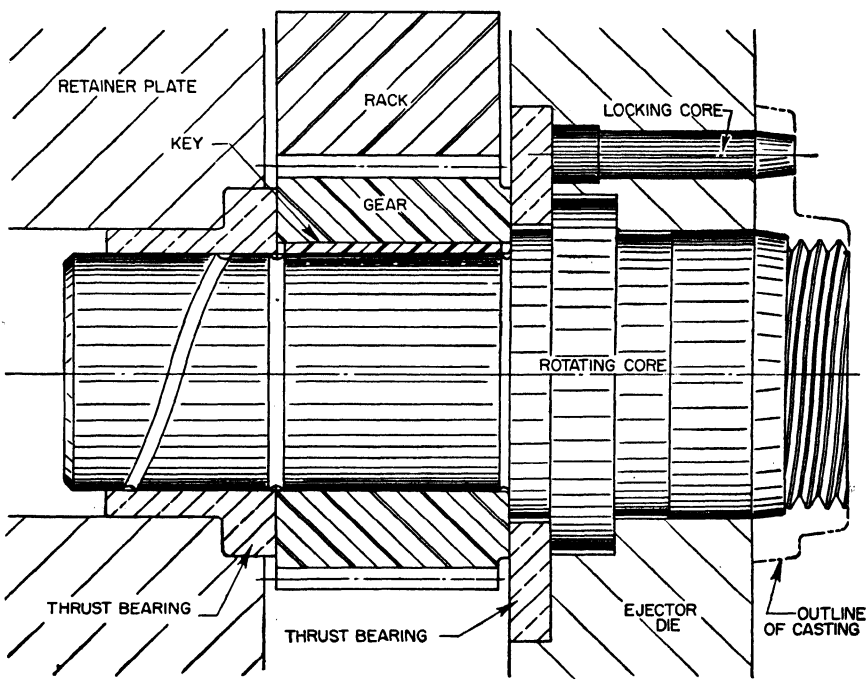


FIG. 4.35. Method of casting internal threads. At the end of the cycle, the core is rotated with a rack-and-pinion mechanism. Internal threads usually are cast only if very steep and coarse pitched.

THREADS

Internal threads may be cast by means of a rotating core, as shown in Fig. 4.35. If the casting is round or has no other means of anchoring, a small core may be added as shown in the illustration. This keeps the casting from turning as the main core is rotating. The casting is automatically ejected by the unscrewing action of the rotating core. The core is rotated by means of a gear, which is keyed to it, and by means of a mechanically or hydraulically operated rack and is held in place by means of thrust bearings. An oil groove should be ground into the core body for lubricating purposes. These cores are occasionally used for very steep, coarse pitched threads when the pitch diameter is over 3/4 in.; the thread can be carried right down to a shoulder or to the bottom of a blind hole, which is not feasible in tapping. All holes requiring finer threads are tapped.

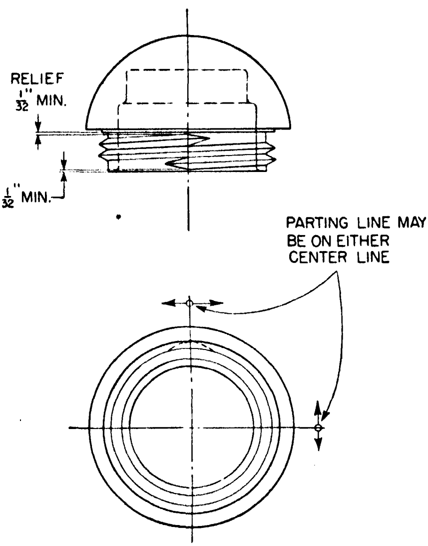


FIG. 4.36. Casting of external threads is done with two side slides, each of which forms half of the thread circumference. When the slides are withdrawn, the casting is ejected in the usual manner.

External threads can be cast in all alloys, provided that they come at a parting line, if the pitch is no more than 24 per inch for zinc, aluminum, and magnesium; 16 per inch for the copper alloys; and 32 for the lead and tin alloys. They are usually formed by a split section of the die, as shown in Fig. 4.36, a small fin being formed where the split or parting is made. The thread must be chased subsequently if a close fit with the mating part is required.

External threads may be cast without a fin by the use of a nut which is held in the die while the metal fills its inside; the nut is withdrawn with the casting and then is unscrewed. Obviously, however, this method is too slow to be economical.

Die-cut threads are more nearly perfect in form, size, and finish than die-cast threads. Many threads are used as cast, or with little chasing except for rough fins being removed where high accuracy is not required.

Shrinkage of the metal when solidifying is apt to cause an error in pitch, but usually this is not significant unless the thread is long.

ENGRAVING AND LETTERING

In many instances the designer may require engraved or decorative designs on the surface of a casting. So long as the impression can be machined or pressed in the die or formed by other methods (photoengraving is practical in some cases), and so long as the designs are not

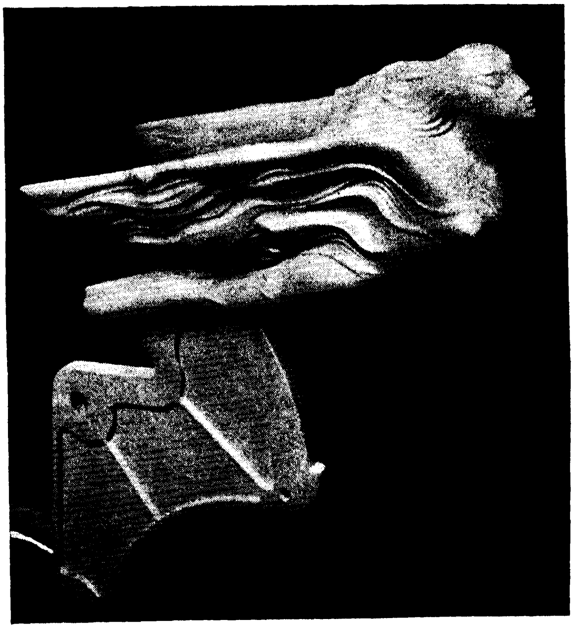


FIG. 4.37. The fine detail possible on die-cast surfaces is utilized for automotive ornaments, dishes, cigarette lighters, and numerous other articles.

undercut in the die, the part can be die-cast. As a matter of fact, many parts for household appliances are cast with a decorative design of some sort on the surface. Small aluminum dishes, serving trays, cigarette lighters, cream and pitcher sets, candlesticks, hood ornaments for automobiles, and automotive radio grilles are a few other parts that are often made with intricate details. The entire casting may be a replica of a symbol, coat of arms, animal, or figure, such as the ornament shown in Fig. 4.37.

However, letters, numerals, and trade-marks are by far the most fre-

quently called for in surface marking, and they are easily and cheaply formed in die castings. In casting engraved letters, it is desirable to

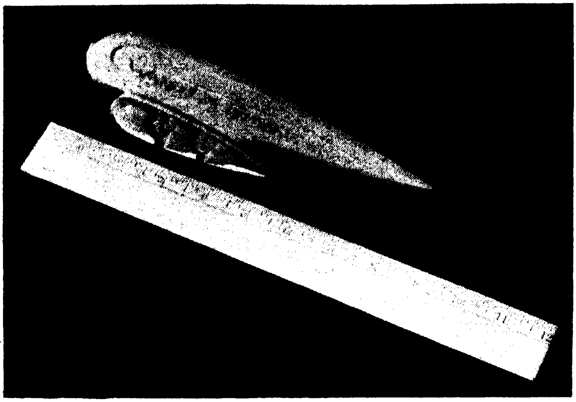


FIG. 4.38. One method of obtaining flush lettering is to recess the panel on which the lettering appears. Recessed lettering can be cast, but die cost is higher and die maintenance more difficult.

allow the engraving to be raised on the surface of the casting. The reason for this is obvious. If letters are depressed in the casting, they

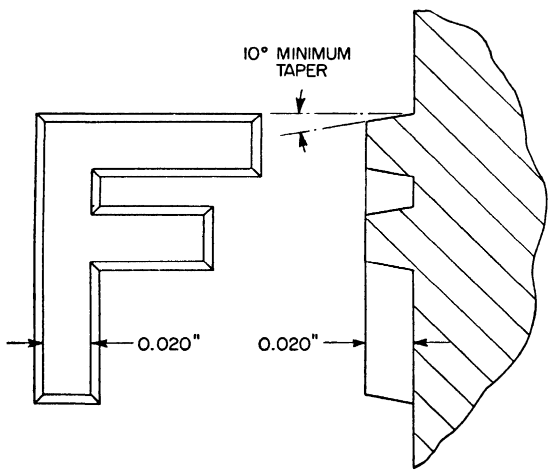


FIG. 4.39. Recommended design for block letters; a ratio of 1½:1 of depth to width is an economical minimum.

must be left standing in the die cavity and are likely to burn or wash off, depending, of course, upon how small they are. If it is desirable to keep

the engraving flush or below the surface of the casting, the engraving may still be cast raised on a depressed panel, as shown in Fig. 4.38.

Rounded ends and corners make for less expensive engraving than square or sharp corners, especially with fine lettering. The depth of the letters should not greatly exceed their width. A ratio of 1½-in.

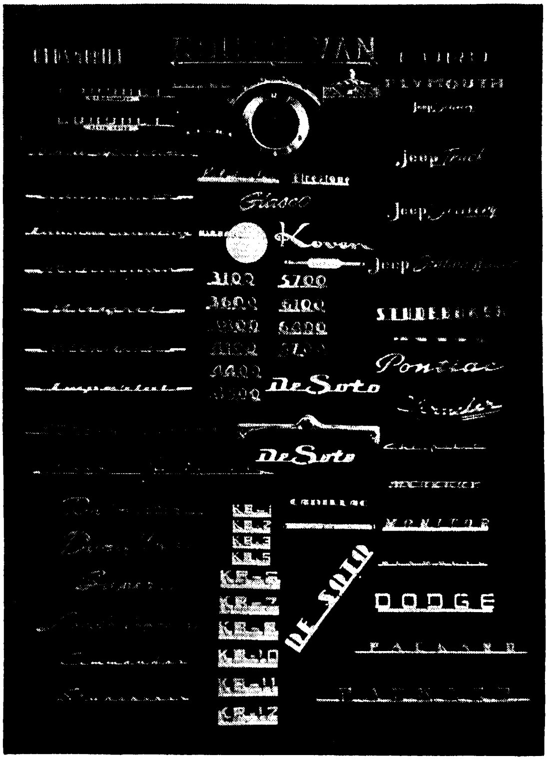


FIG. 4.40. Die-cast name plates, showing a variety of different types of lettering.

depth to 1-in. width is an economical maximum; much larger draft is required than for die-cast walls and cores. A minimum angle of 10 deg on a side and a minimum width and height of 0.020 in. are recommended for most satisfactory results, as indicated in Fig. 4.39.

This is not meant to imply that recessed letters cannot be cast, for they can and often are. Also, name plates for automobiles and appliances such as electric stoves and refrigerators often consist only of lettering either in script form or in block form; a base or metal strip through the letters being required in the latter case. The letters may follow a straight line, an arc, or an angle or may even be cast in three planes

(Fig. 4.40). But as the complexity increases, so does the cost of the casting die and trim die, and scrap losses also will increase. Whether such lettering, numbering, or marking is justified or not is strictly a matter for the designer to decide: If the effect that they create is striking enough to overbalance the additional cost, then by all means they should be used.

ELECTROPLATED PARTS

In parts that are to be electroplated, deep, narrow closely spaced ribs entrap buffing compound and are difficult to clean properly. Front faces absorb most of the plating current, making it difficult to plate between the ribs. Failure to plate such areas results in contamination of the bath, which causes serious difficulty. Ridges that are parallel to the direction of motion of the casting when it is moved against the polishing and/or buffing wheel, as well as valleys between ridges similarly disposed, are much easier to polish than if placed across or at an angle to such motion. Recesses or depressions which are to be plated should be shallow—if too deep, gas will be entrapped from the plating bath. Such areas will not be properly plated, and the flow of excess gas over the surrounding areas may cause peeling and poor appearance. Sharp corners and points should be avoided because deposits on such places tend to be rough and brittle. Generous radii and angles avoid the necessity of applying excessively thick deposits on such areas; it is well to remember that large concave areas are difficult to plate because of low current density at the center, and convex shapes are easier to plate than flat shapes.

Many other conditions must be met if a part is to be plated satisfactorily, especially if it is to be exposed to severe atmosphere or corrosive conditions in service. These requirements are discussed in detail in Chap. 8, Finishing of Die Castings.

DESIGNING FOR ECONOMY OF PRODUCTION

The possibilities of keeping the cost of die castings down have already been partially covered by the remarks on inserts, undercuts, coring, metal sections, tolerances, and drafts. There are, however, other possibilities which are generally not so obvious to the designer. The designer can bring the cost down by keeping in mind that his design will materially affect the cost of dies (as to original cost and life) and the cost of trimming the casting, which is likely to run into considerable figures unless it has been given careful consideration in the design.

As to the cost of the die and its life, contours that make dies expensive are those which cannot be produced through the rotation or traverse of machine tools. Expensive repairs are avoided by designs which can be

made in dies without delicate parts, extensive coring, or loose pieces. Weak die sections, such as thin, deep recesses, knife edges, and sharply recessed corners, are apt to shorten the life of the die.

Designs which call for cores to extend across the parting line should be avoided, since differences in thermal expansion and other factors may cause misalignment in the holes through which the core is to pass.

Other rules that, if practical for the part under consideration, will help to keep costs at a minimum are included in the following listing. Many of these are rather elementary, yet surprisingly few designers take them into consideration when developing a part.

One should realize, of course, that often the design of the part is such that these suggestions are impractical; and also that while movable cores, loose die parts, and other complex constructions add to die cost and slow up the casting cycle, the cost of the die casting still usually is less than if the part were made by some other method of production. In brief, it may be far simpler to use complex dies and die-cast the part than to make it by another method.

In general, the designer should

1. Select a low-melting-point alloy so that die life is long. However, service requirements for the part are the primary governing factor in so far as alloy is concerned.
2. Design the part so that the parting line is in one plane; trimming costs thus are minimized.
3. Provide minimum wall thickness, consistent with the requirements for part strength and stiffness and with the practicality of die manufacture.
4. Keep wall thickness uniform so that die fill is uniform.
5. Avoid thin sections that may slow up solidification of the casting and create stresses and porosity when the casting cools.
6. Provide shallow ribbing on large flat areas to minimize distortion and improve the flow of metal into the die.
7. Avoid holes and undercuts that must be cored by movable die members or removable die parts.
8. Eliminate intersecting holes or passages that would require the use of intersecting cores. If this is unavoidable, then the one core should be at least twice the diameter of the core passing through it.
9. Consider the use of inserts to form curved passages or to add strength at sections that otherwise would require heavy walls.
10. Balance the cost of punching, piercing, or drilling holes and openings, or of tapping or cutting threads, against the cost of casting them. Similarly, balance the cost of machining slots and milling flats against the cost of casting them.

11. Use cores as metal savers whenever possible.

12. Provide adequate space between holes and slots and thus eliminate thin walls that may cause heat checking of the die.

13. Avoid the use of long slender cores, especially those that form blind holes.

14. Avoid angular holes in the plane of die parting, because such holes require special core-pulling devices.

15. Avoid curved cores, which must be pulled along an arc.

16. Provide sharp internal corners at the intersections of two cores, for otherwise loose pieces or revolving cores are required.

17. Minimize shrinkage stresses on die parts and cores that are far apart by specifying bosses, ribbing, or beading.

18. Provide adequate draft on walls and cored holes, as recommended in Table 4.1.

19. Provide large taper on walls that have openings or windows so that such openings can be formed by the two die members.

20. Specify adequate radii on ribs and bosses. Sharp corners and flat tops cause short die life and are difficult to machine.

21. Provide uniform radii whenever possible, because different radii require different milling cutters and therefore increase die cost.

22. Specify radii on all bosses and at all corners except those on the parting line. Again, sharp corners are expensive to form and difficult to maintain.

23. Specify regular curves and contours that can readily be machined.

24. Avoid sharp corners and deep projections that may trap air and retard the flow of casting material.

25. Provide stops or plenty of draft on loose cores so that they can be easily pulled on completion of the casting cycle.

26. Consider the use of inserts whenever the part must be fastened to other parts to form an assembly after casting.

27. Specify raised lettering, because recessed lettering necessitates small, thin die projections that become worn in service.

28. Provide large tolerances, especially when the dimensions are to be formed by both die members. Since the two halves of the die may be forced open by the pressure of the injected metal, it is only logical that closer tolerances can be maintained in one half of the die than across both halves.

29. Estimate the cost of producing a complex casting in two or more sections as against that of producing it in one die and vice versa.

30. Always bear in mind that the simpler the design, the more economical the part. Fancy shapes, although pretty from an artistic point of view, require a longer time to build, resulting in a higher die cost and more expensive cleaning tools. This all results in a higher piece price.

Figure 4.41 illustrates three similar shapes. It is apparent why the part shown at *C* is simpler than the other two and would therefore be the least expensive.

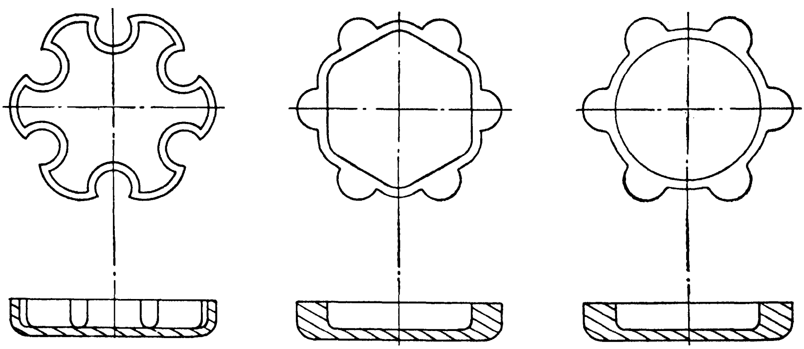


FIG. 4.41. Complex contours add to die cost and make necessary more expensive cleaning tools. Since the dies for part *C* would be simpler and could be made with standard rotary cutters, it is the most desirable form.

CUSTOMER'S DRAWINGS

The average designer is not an experienced die caster, and although an attempt has been made to acquaint him with the most essential characteristics of die castings and the die-casting process, it would be impossible to teach him all the "tricks of the trade" which the professional die caster has acquired and which enable him to handle successfully all kinds of specific problems as to gating, venting, die parting, coring, etc. Close cooperation with the die caster is highly advisable in order to overcome troubles; dies, cores, etc., are quite expensive, and changes in them subsequent to getting into production are likely to involve additional expense which may seriously affect the economic advantages of die casting. By the same token, of course, the designer should be sure that the design is definitely settled and not subject to early change owing to shifting sales sentiment or to service troubles. If there is any uncertainty about the stability of the design or its serviceability, it is advisable to handle production during the introductory period with sand castings or some other less restricting method of manufacture.

The designer should give full and complete information to the die caster on the following points. He must

1. Indicate clearly plus and minus tolerances (as liberal as possible)

on all parts which are to be used without machining and where only a certain variation from the optimum dimension is permissible.

2. Indicate direction and maximum permissible draft on wall sections where assembly requirements demand it.

3. Indicate all sections which are to be machined, stating the dimensions to be obtained in machining, so that the die caster can furnish necessary machining allowances (this will largely depend upon several variable factors).

4. Indicate any special requirements (and where needed) not usually considered a commercial standard, such as

a. Leakage resistance and nature of the leaking medium: gas, air, oil, etc.
b. Other than atmospheric temperature, high or low.
c. Freedom from porosity in any section which must be drilled or tapped without coring.
d. Freedom from surface marking such as caused by ejector pins, parting-line flashes, run marks, etc.
e. Where flat surfaces must remain undistorted.
f. Surfaces which must be electroplated, anodized, etc.
g. Where special strength requirements must be observed and their nature: torsion, bending, twisting, tension, hardness, etc.
h. Any special corrosion exposure, other than ordinary indoor atmosphere: exposure to humid atmosphere or sea water; marine, mine, or industrial use; contact with foods, beverages, or chemicals; etc.

The more information that is given to the die caster, the better will he be able to produce a satisfactory casting and to prevent later troubles and complaints for which he cannot be held responsible, not having known about the requirements. Unless he is informed otherwise, he will supply commercial die castings which are not supposed to "take care of special needs."

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CHAPTER 5

COMPARISON OF DIE CASTING WITH OTHER PRODUCTION PROCESSES

So many factors enter into the selection of a process for the production of an individual part that it is almost impossible to list them, let alone discuss each one. It should be understood, therefore, that comparisons such as are made in this chapter are for the sole purpose of broadly indicating the general field of application of die casting. All the comparisons are generalizations, and as such are dangerous if used to make a selection for any specific job; for each application, an engineering analysis should, and must, be made.

Certain fundamental considerations must be analyzed by the designer, however, before he designates the method by which a part should be made. Among the most important of these are the following:

1. Whether the material from which the part is to be made can be shaped by the proposed process, or whether the part would function satisfactorily if made from a material that definitely can be economically shaped by the process.
2. Whether the required rate of production can be met.
3. Whether the design and complexity of the part represents a limitation.
4. Whether the size and weight of the part represents limitations.
5. Whether parts of the required strength can be obtained.
6. Whether the required tolerance can be held.
7. Whether the desired part appearance and other necessary properties can be obtained.
8. Whether plant facilities are available for production, or whether the parts can be readily obtained from an outside supplier.
9. Whether the parts can be put into production within a reasonable length of time.
10. Whether the process is economical, based on the unit cost of the part and on the number of subsequent operations that might be required to finish it.

The basic difference between the die-casting process and "competing" methods of manufacture, in so far as these points are concerned, is sum-

marized in the remainder of this chapter. Competing production processes—depending upon the type and requirements of the individual job—will be considered as permanent-mold casting, sand casting, plaster-mold casting, precision-investment casting, the powder-metallurgy process, plastic molding, stamping and drawing, screw-machine production, and drop forging and die pressing.

MATERIALS

Most of the processes previously referred to can be used to shape or form parts made from both ferrous and nonferrous metals, principally

FIG. 5.1. Aluminum, zinc, and magnesium castings for vacuum-cleaner parts. Copper-, tin-, and lead-base alloys also are die-cast, but in lesser quantities.

aluminum, magnesium, and zinc (Fig. 5.1). Plastic molding is one exception. Plaster-mold casting cannot be used for ferrous metals, nor can die casting. Although steel has been die-cast, the problem of finding a suitable die material has never been satisfactorily solved; consequently,

die casting of steel is more of an experimental than a practical production process at the present time.

Conversely, most sand casting is done with cast iron or cast steel, and precision-investment casting is generally conceded to be useful mainly with high alloys of iron—Inconel, stainless steel, Hastelloy, and special high-temperature-resisting materials—and with precious metals. Some zinc, magnesium, aluminum, and copper is precision-cast, but the quantity is exceedingly small. Similarly, powder metallurgy is concerned mainly with iron powder or with copper-alloy powder. Materials commonly shaped by other processes are listed in Table 5.1.

TABLE 5.1. METALS COMMONLY FORMED BY VARIOUS PRODUCTION PROCESSES

Materials	Methods of production									
	Die casting	Permanent-mold casting	Sand-casting	Plaster-mold casting	Precision-investment casting	Powder metallurgy	Plastic molding	Stamping and drawing	Screw-machine production	Drop forging and die pressings
Iron (pure)						X				
Cast iron		X	X		X					
Malleable iron			X							
Tin alloys	X	X								
Lead alloys	X	X								
Zinc alloys	X	X								
Aluminum alloys	X	X	X	X	X			X	X	X
Copper			X		X	X		X	X	
Copper alloys:										
Brass	X	X	X	X	X	X		X	X	X
Bronze			X		X	X		X	X	
Steel:										
Carbon steel			X					X	X	X
Low-alloy steel			X		X			X	X	X
High-alloy steel			X		X			X	X	
Nickel and nickel alloys			X		X			X	X	X
Thermosetting and thermoplastic plastics							X		X	
Gold				X	X					
Silver				X	X					
Platinum				X	X					
Magnesium	X	X	X		X			X	X	X

RATE OF PRODUCTION

Speed of production of die castings is one of the major advantages of this process. The number of shots possible with a modern die-casting machine depends upon the material: It is high with low-melting-point alloys and progressively lower with higher melting point alloys. It also varies with the size of the casting; its complexity; the number, shape, and location of the cores and inserts; and special requirements.

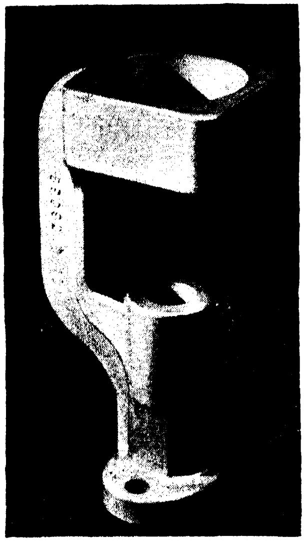


FIG. 5.2. Magnesium bolster for a ball-bearing spindle weighs 0.384 lb, measures 6 in. in height, and is cast on a 45-sec cycle.

Several hundred shots per hour is not unusual when die-casting small, relatively simple shapes from low-melting-point alloys. Even with larger, more complex shapes the casting cycle is short; the magnesium part shown in Fig. 5.2, which weighs approximately 0.384 lb and measures roughly 6 in. over-all, is cast on a 45-sec cycle. Definitely, then, die casting is a high-production process and therefore is generally not economical for parts made in limited quantities.

As a general proposition, the rate of production of die castings is higher than for corresponding parts made by any of the other casting processes: plastic molding, drop forging (except of very simple shapes), die pressing, and stamping and drawing (again except of simple shapes). It is, however, apt to be somewhat lower than for parts made on automatic screw machines and on automatic powder-metal presses. Molded thermoplastic materials of simple shape are nearest in speed of production to die casting; thermosetting resins must be cured before being removed from the press and so require a considerably longer time to produce. Sand casting, plaster-mold casting, and precision-investment casting generally are not considered to be high-production processes.

PART DESIGN AND COMPLEXITY

Another outstanding advantage of the die-casting process is that complex shapes can be made that would be difficult, if not impossible, to obtain by any other method—at least in large quantities. By the use of

sliding die members, undercuts and intricate holes can be formed in the part. Examples illustrating the degree of complexity that can be obtained are shown in Fig. 5.3.

For permanent-mold casting, gravitational forces are relied upon to pull the molten metal into the mold cavities. Only if centrifugal molds are used do the applied forces approach those common in die casting,

FIG. 5.3. These functional automotive parts illustrate some of the complex shapes that can be die-cast.

and as a result the metal cannot be forced in and around intricate passages and cores. Thus, the complexity of the parts that can be obtained is generally less than that obtained by die casting. The same thing is true of sand casting and permanent-mold casting.

Precision-investment castings can be made exceedingly complex, but the process usually is suitable only for small parts—7 in. or less in one dimension. The powder-metallurgy process to date has been limited to the production of relatively small and simple shapes with coring in one direction and with no undercuts, although this conceivably may change

as more is learned about production techniques. Forgings and stampings have the same limitations. Screw-machine parts often are very complex; but the greater the complexity, the more expensive the tooling, the longer the production time per piece, and the greater the cost. Plaster molding is about on a par with die casting in this respect.

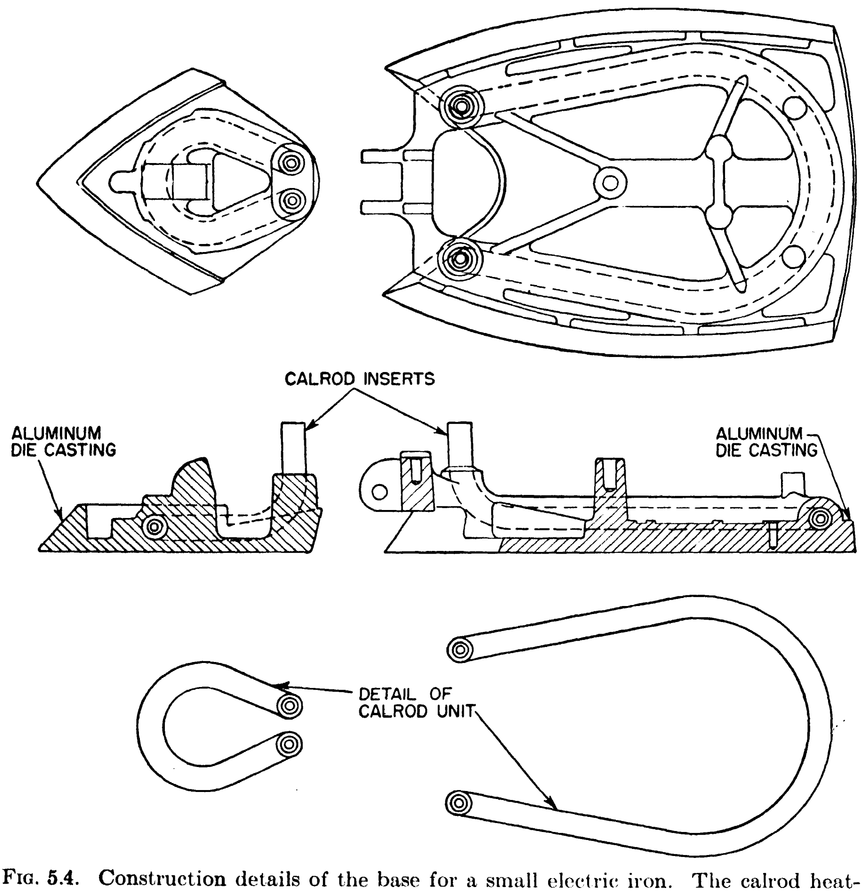


FIG. 5.4. Construction details of the base for a small electric iron. The calrod heating elements are inserted in the die before the shot is made, and are thus made integral with the base.

INSERTS

Inserts, made in a wide variety of shapes and of almost any metal, can be used in die castings, imparting to the castings mechanical and physical properties foreign to the base metal (Fig. 5.4).

Sometimes even complicated parts, separately fabricated, can be em-

bedded in the casting, whereas if the same structure were cast as a part of the casting body it would be a prohibitive addition to the cost of the die and to the difficulty of obtaining a good commercial article.

In many cases, these inserts make possible the combination of a number of constructional parts of a mechanism or apparatus into one self-contained unit without the need of fitting and joining several individual pieces. With other casting processes, a certain amount of such combinations also is possible, but to a lesser extent, especially with regard to

FIG. 5.5. Thin-walled magnesium die casting, which is recognizable as a phonograph arm. Strength, not thinness, is usually the limiting factor in arriving at satisfactory wall size in so far as die casting is concerned.

inserts. The rapid extraction of heat from the molten metal by the die largely eliminates the danger of drawing tempers, fusing, softening, charring, discoloring, and distorting inserts. In zinc (which in cast form becomes a mechanically useful material only when die-cast), the thermal effect of the molten metal on inserts is so low that even paper inserts can be utilized.

SECTION THICKNESS

The minimum thickness of die-cast walls varies inversely with the melting point of the material. It also depends upon the fluidity of the metal and upon the size and shape of the casting. The possibility of casting thin sections of more than average strength (Fig. 5.5) is a distinct advantage of die casting, aside from the commercial feature of saving material.

Permanent-mold castings are affected by chilling of the molten metal by the mold, as also are die castings. But since permanent-mold castings lack the driving force behind the metal, as in die casting, the speed of

travel of the molten metal through narrow passages of the mold is less, and the danger of premature freezing of the metal stream when traversing thin passages between mold walls is more, thus militating against making the passages too thin.

The same reasoning about the lack of pressure back of the metal as it affects section thickness applies to sand casting. In a cored section, when there is danger of the core shifting, the wall thickness must be greater than in die or permanent-mold castings to compensate for possible unevenness. Furthermore, rapping of the pattern in sand may increase the final thickness of the section. Sections commercially producible in sand castings, for the same design and corresponding metal, must be thicker than in permanent-mold castings and even more so than in die castings.

Plaster-mold castings are made in a mold of low heat conductivity—lower than sand and much lower than the steel molds and dies of die and permanent-mold castings. The danger of premature freezing in thin sections is lessened, so that extremely thin sections might be anticipated. On the other hand, rapping of the pattern and the unpredictable shrinkage of the plaster mold during curing after the pattern has been withdrawn are a handicap. The minimum section thickness of plaster-mold castings, therefore, is only comparable with die castings of aluminum and magnesium; it is greater than in zinc, tin, or lead die castings, but less than in permanent-mold and much less than in sand castings.

Precision-investment castings, which usually have, besides a low-heat-conductivity mold, the additional advantage of a moderate driving force imparted to the metal by centrifugal action, can be cast in thinner sections than plaster-mold or die castings. Edges or fins on pieces of continuously increasing thickness such as knife blades or turbine blades, can be made as thin as 0.015 in. in highly castable alloys.

Plastics lend themselves most economically to the molding of relatively small objects having thin walls of fairly uniform section. Commercial thicknesses under such conditions are apt to be somewhat less than for the aluminum, magnesium, and copper-alloy die castings, but about comparable to the lower melting point die-casting alloys like tin and zinc. The low mechanical strength of plastics operates against the use of very thin sections except when the parts will be lightly loaded in service. Stamping and punchings being made from metal sheet or strip can, of course, be made in thinner sections than in die castings.

Screw-machine sections may be turned with thinner edges and fins than die castings. Forgings and die pressings obviously cannot be made in such thin sections as die castings. In powder-metal parts, the minimum thickness of a section is rarely less than $\frac{1}{32}$ in.; when the pressure

is at right angles to the section, the wall thickness usually should not be less than 1/25 of the length.

As to limitations of thickness of section, the only general rule for die castings is this: If the section is too heavy, exceeding 1 in. or so, the structural uniformity of the section suffers. There is a rather steep chilling gradient from the outside to the center of the casting, thus causing a considerable variation in grain size and mechanical strength. Also, the danger of internal porosity increases with the thickness of the section. Unduly heavy sections should be avoided; and when mechanical strength or stiffness must be high, thinner sections with judiciously placed strengthening and stiffening ribs should be used instead (see Chap. 4, Design of Die Castings).

In permanent-mold castings, heavier sections can be cast than in die castings with less danger of variations in section structure and internal porosity, although even in such parts, heavy sections when fed through a thin section present a problem. In sand casting where chills, risers, and multiple gating can be utilized, even larger sections can be cast, although the mechanical unit strength of a heavy section is still apt to be less than that of a thinner section.

In plaster of paris castings, in which the slow cooling of the metal in the mold makes for greater structural uniformity of a section (although with lower unit strength than die or permanent-mold castings), quite heavy sections can be cast, limited only by equipment. In precision-investment castings, the thickest preferred sections are about 3/8 in., since the wax of plastic patterns becomes liable to excessive expansion and contraction when made heavier and thus may strain or break the investment. In molded plastic parts, maximum wall thickness is rather limited; the preferred maximum thickness is from about 1/8 to 5/16 in., depending upon the character of the plastic and upon the method of fabrication.

In formed stampings and punchings, the maximum applicable thickness of the stock will depend upon the nature and degree of deformation; on the temper of the material; and on the ductility, yield strength, and work-hardening tendencies of the material. In general, sections could be made as heavy as in die casting; but because of the higher inherent strength of wrought material, it is rarely necessary to duplicate the thickness of section required in a casting of comparable design and composition.

In forgings, the maximum thickness depends upon the equipment available and on the material. For comparison with die castings, it may be said that any metal forging and die-pressed part can be produced in much heavier sections than die castings.

In screw-machine work, the maximum recommended thickness is somewhat heavier than for die castings. Wrought materials, in general, tend to lose some unit strength with increasing section thickness.

In powder-metal work, the permissible thickness of a section depends upon such a multitude of factors that a general statement is inadvisable. If the section is so thick that it must be compressed from top and bottom, it is apt to have a low density in the center. Under favorable conditions of uniformity and area, sections of as much as 1 in., and sometimes more, may be made.

STRENGTH OF PARTS

In comparing one metal with another, or in collating the processes by which metals are formed, it is important to consider the matter of grain or crystal size. The size of individual grains in cast metals varies greatly by the rate at which solidification from the molten state occurs. Slow cooling of a melt results in large-sized grains, while rapid chilling produces fine-grained structures.

Casting in sand molds or other refractory mold materials causes slower rates of cooling than does casting in metal molds of relatively higher heat conductivity. Therefore the grain size of a sand casting always is considerably larger than castings produced in metal molds. The rapid chilling effected by the pressure-die-casting process produces the finest grain structure of any of the casting methods.

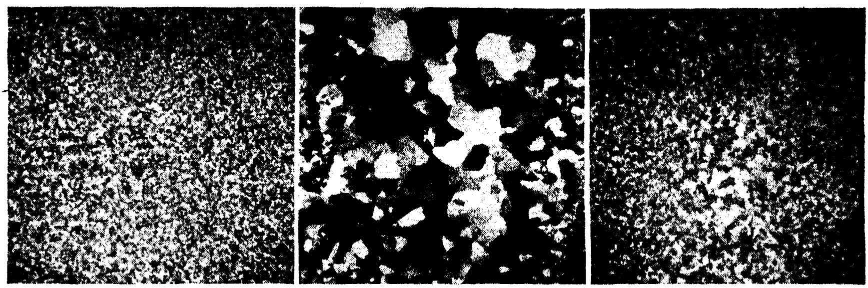
As a result of the fine grain inherent in pressure die castings, there is never a need for any grain-refinement treatments of the metal or alloy such as are necessary in the casting of metals by other methods. In pressure die casting there is no necessity for any such treatment as "modification" of the high-silicon (12 per cent) alloy, mandatory when this alloy is cast in sand molds. In the die casting of magnesium alloys, the superheating of the metal to refine grain size, compulsory for other methods of casting, is neither required nor practiced. Similarly, the use of any of the other refining agents and treatments for casting metals does not apply to the die-casting process.

The average grain size of die-cast structures is on the order of 0.0005 in., which is compared with the grain size of 0.020 to 0.050 in. for permanent-mold castings and from 0.050 in. up for sand castings. Figure 5.6 illustrates the grain size of metals when cast under different casting methods.

Because of the fine grain structure obtained by the rapid chilling of the metal in the die, die castings have an "as-cast" strength that is greater

than that of castings produced by any other method, provided, of course, that they are made of the same material. Age-hardening alloys, when given a low-temperature heat-treatment or when aged for a protracted period of time in air, have tensile properties approaching those of fully heat-treated permanent-mold castings. Other die castings, which usually are not heat-treated due to the danger of blistering and swelling, have somewhat lower strength than fully heat-treated permanent-mold castings.

Heat-treated sand castings seldom exceed the strength of a good die casting. In the as-cast condition, plaster-mold and precision-investment



a *b* *c*

FIG. 5.6. Grain size of cast metals. For the same materials, the smaller the grain size, the greater is the strength. *a*. Die casting. *b*. Sand casting. *c*. Permanent-mold casting.

castings are less strong than sand castings, although some aluminum alloys, such as aluminum-zinc-magnesium alloys and most copper alloys, will equal the strength of a sound sand casting.

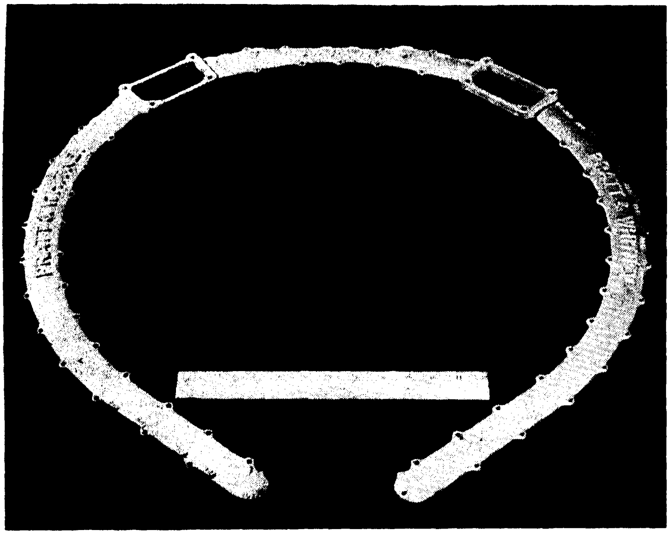
Die castings also have better mechanical properties than plastics (tensile strength, ductility, elastic limit, shock resistance, modulus of elasticity, creep strength, and thermal expansion) and are stronger than nonferrous powder-metal parts. They are not so strong, section for section, as wrought metals produced as stampings or forgings.

SIZE AND WEIGHT OF PARTS

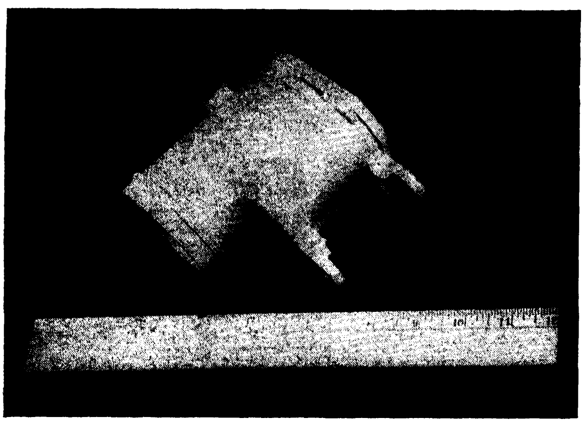
As previously indicated, although not specifically stated, in the discussion on die-casting applications, the range of size of die-cast parts is from very small (business-machine parts) to large (housings and frames for appliances, tape recorders, and automotive components). Actually, the limitation is not so much on the size and weight of the parts as it is on the quantities in which it is to be made. As size increases, the quantities in which nonferrous metal parts are required decreases, thus making

it unprofitable to produce them by die casting. In Fig. 5.7 are shown parts that represent the average size range of die castings.

The maximum weight of die-cast parts is usually below about 15 lb for aluminum-base alloys, 10 lb for magnesium-base alloys, 25 lb for zinc-base alloys, 5 lb for copper, 15 lb for lead, and 10 lb for tin. In general, parts made on automatic screw machines by the powder-metallurgy process, by precision-investment castings, and by plastic molding



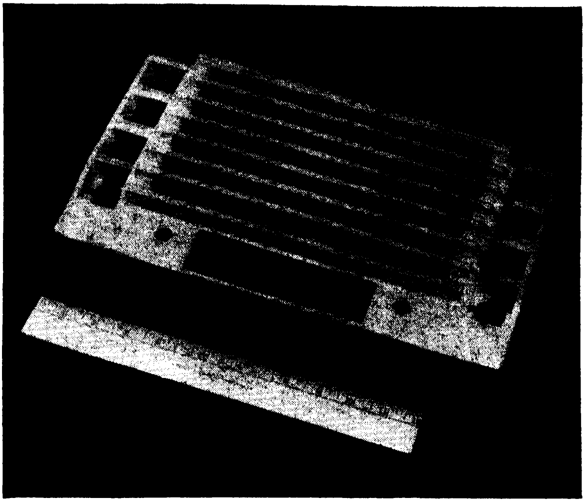
a



b

Fig. 5.7. The size of die castings ranges from small button-sized components for business machines to automotive grilles. Here are castings that represent common

are smaller and lighter in weight. Plaster-mold castings are usually small, although they can be cast in fairly large sections. Permanent-mold castings, drawn parts, drop forgings, and die-pressed parts can be made in much larger sizes than can die castings, and sand-cast members are made in an extremely wide range of sizes and weights.



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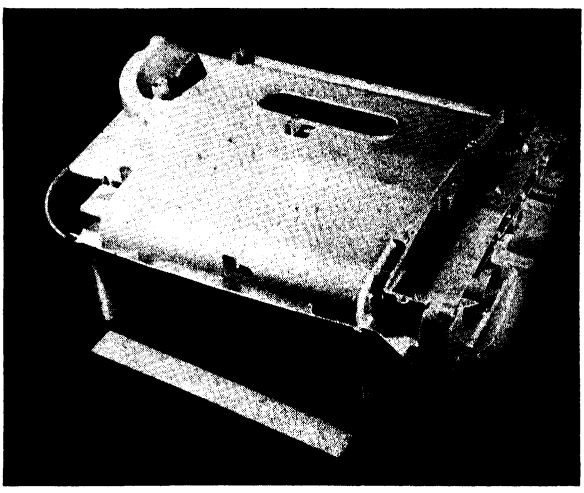


d

sizes: *a*, magnesium aircraft part; *b*, magnesium binocular case; *c*, zinc radio grille; and *d*, aluminum frame member.

TOLERANCES BEFORE MACHINING

Die castings can be produced commercially to closer dimensional tolerances than is possible with most of the other listed processes, with a corresponding saving of machining time and materials.

In this respect, they are superior to permanent-mold castings, which are broadly on about the same level. Screw-machine parts produced on hand machines can be made to closer tolerances than die castings.

These statements are generalizations, especially in regard to molded plastic parts and precision castings, where under special conditions of shape, section thickness, and section size the picture may sometimes be reversed. Also, in the case of lead-, tin-, and zinc-base alloys, comparisons of tolerances may be weighted even more in favor of die castings over other processes.

APPEARANCE OF PARTS

The question of the appearance of manufactured parts can be summed up by stating that many die castings can be plated, painted, or chemically coated after only a buffing operation, and—depending upon the application—even this operation may be unnecessary. With parts produced by only a very few of the other processes is this possible, and none lends itself quite so well to the multitude of finishes that can be used on die castings.

This surface smoothness not only creates eye appeal, but in some cases has a definite functional advantage in that it may reduce friction. Examples are gas meters, where efficiency is increased by a decrease in the turbulence created by the flow of the gas over the surface, and gyroscopes, where even small surface variations would sometimes be sufficient to upset the delicate balance.

In these respects, die castings are superior to permanent-mold and, to even greater degree, sand castings. They are about comparable to plaster-mold and precision-investment castings and to powder-metal parts. They are not quite so glossy and smooth as plastics, which have the advantage of opaqueness, translucidity, transparency, and various colors—although these colors sometimes fade when exposed to sunlight for extended periods. If scale is removed on forgings and die pressings, the surface is usually comparable to die castings. Part outlines and contour changes, however, are less sharply defined than in die castings or other forms of castings, and therefore considerable additional machining may be necessary. Die-pressed parts are somewhat better than forgings in this respect.

OTHER PART PROPERTIES

Besides strength and appearance, there are a host of other properties that may be important in a particular application. Dimensional stability may be one of these; resistance to elevated and subnormal temperatures and resistance to leakage may be others.

Dimensional Stability. The dimensional stability of die castings depends upon several factors: the degree to which aging affects the volume of the material that is used; the number of locked-up stresses that are present in the part; the temperatures to which the parts are subjected during finishing and in service; the severity of subsequent machining operations; and the tendency of the metal to creep under load.

The aluminum- and magnesium-base alloy die castings are very stable dimensionally and are not subject to permanent growth. Zinc alloys are subject to a small dimensional change on aging (shrinkage followed by expansion); in the case of the copper-free alloys, this results in shrinkage; and in the case of an alloy with about 1 per cent copper, in a slight expansion. After 2 years at about 200°F in dry air, the ultimate change for the copper-free alloys is on the order of minus 0.0002 in. per in. These changes are so slight that they generally can be ignored, but if it is desirable to speed them up so that relatively little change occurs after machining, a stabilizing heat-treatment can be resorted to.

Dimensional changes resulting from locked-up stresses appear generally as distortion, warpage, and misalignment. They are, as a rule, caused by failure to freeze the whole casting progressively. As a result, internal stresses are set up between sections of unequal thickness because of unbalanced contraction during solidification, or because the natural path of solid contraction is forcibly restricted by sudden changes of direction.

If the parts are cast from aluminum or magnesium (Fig. 5.8), the "skin" or outer surface of the casting usually is sufficiently tough to restrain the internal stresses; if the parts are to be machined and the skin broken, distortion can be minimized by a low-temperature stress relief before putting them in service. Zinc die castings in which high dimensional stability is required are sometimes quenched immediately on removal from the die in order to harden the skin and increase its restraining power. In copper alloys, where again the difference in strength between skin and core is less pronounced and where the metal itself is strong enough to withstand considerable internal stresses, little trouble is experienced from the release of internal stresses.

Another cause of distortion may be machining, when the tool pressure

is greater than the elastic limit of the section against which it is exerted. If this section is inadequately supported or if the temperature of the casting is raised sufficiently to lower the strength of the material, it will yield and distort; the remedy is obvious: sufficient support of those sections that are susceptible to such effects.

Warpage and distortion resulting from the application of baked finishes are a straight temperature effect. If the baking cycle is too long,

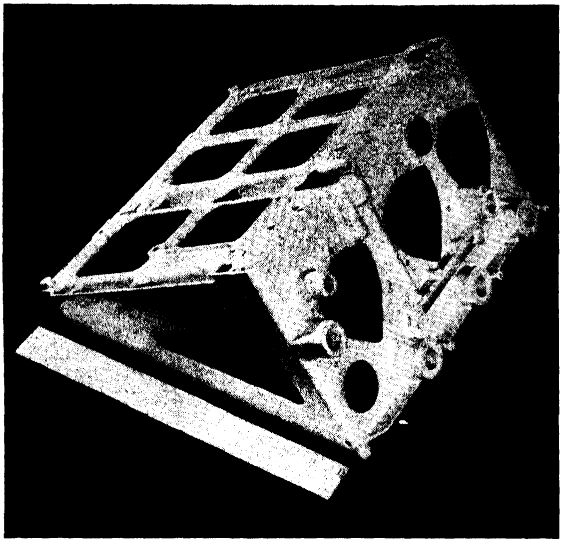


FIG. 5.8. Close tolerances and dimensional stability can be obtained in die casting by proper design. Each of the cored holes and bosses of this part has to be accurately located since it serves as a mounting or locating point in an assembly. The part is a magnesium casting for an automatic aircraft pilot base.

the restraining force of the skin and the inherent strength of the core are decreased to a point where internal stresses cause dimensional changes; therefore, finishing cycles involving baking must be carefully adjusted in order to prevent such troubles.

Creep under load is rarely encountered in the copper, aluminum, or magnesium die castings, unless the castings are overstressed or operated at excessive temperatures. Zinc die-casting alloys have no definite elastic limit below which there is a permanent set, so that gradual creep under any appreciable load must be reckoned with.

All other types of casting are subject to the same conditions of growth as are die castings of similar compositions, although a precipitation heat-treatment can be used to stop any further growth in service. When not given a full heat-treatment, a "stabilizing" treatment at mildly elevated

temperatures suffices. Internal stresses in permanent-mold castings develop along very much the same line as in die castings.

In the case of permanent-mold castings, welding and brazing are another source of internal stresses. The usual treatment is (1) to preheat the whole casting before welding in order to prevent excessive temperature differences between the weld area and the rest of the casting; and (2) to control the cooling of the weld and casting after welding. Dimensional changes in sand castings are caused by growth and by internal stresses, as in die castings, and precision-investment castings are subject to the same growth as corresponding compositions cast by other processes; internal stresses resulting from unequal cooling are apt to be lower than in the other casting processes because the metal is cooled more slowly by the plaster mold. Castings of all processes are, of course, subject to the same troubles when being machined.

Wrought materials, when formed by bending, drawing, and rolling, are also affected by localized stresses, not so much from warpage as from the effect of the operation on mechanical and physical properties of the metal. In some compositions, especially the brasses, internal stresses may even eventually lead to structural failure by intercrystalline corrosion unless relieved after fabrication by an adequate heat-treatment. Distortion may occur when the parts are welded, brazed, or soldered unless heat-treatment is resorted to.

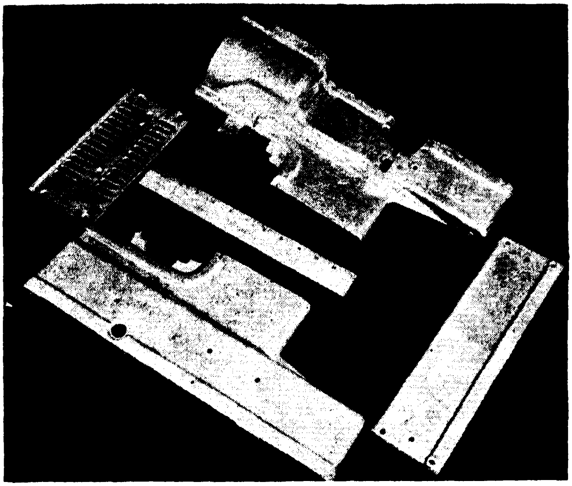
Practically no distortion occurs in powder-metal parts if they are properly sintered.

The dimensional stability of all plastics is adversely affected by exposure to sunlight and by varying humidity and temperature. As humidity changes, plastics are apt to grow or shrink to an extent varying with the material. At relatively low temperatures, plastics will deform of their own accord or decompose (at about 200°F for some resins and at up to 400°F for others). Dimensional changes are also likely to occur as the operating temperature approaches the softening point.

Dimensional changes as the result of creep are not likely to affect metallic materials used in any of the listed processes—outside of zinc-, tin-, and lead-base die castings—if stresses and temperatures are kept safely below the permissible load limit. Plastics are more susceptible to creep than any of the metallic materials that have been discussed.

Resistance to Elevated and Subzero Temperatures. In commercial die castings, the structure is apt to be porous, especially when the sections are heavy, or to contain a considerable amount of entrapped air in the form of small nodules distributed throughout the section. When the temperature of operation exceeds about 500°F, the air entrapped in the structure expands. Since the metal at this temperature has lost some

of its initial strength, the expanding force may be great enough to cause blistering and swelling of the surface—the same effects as caused by



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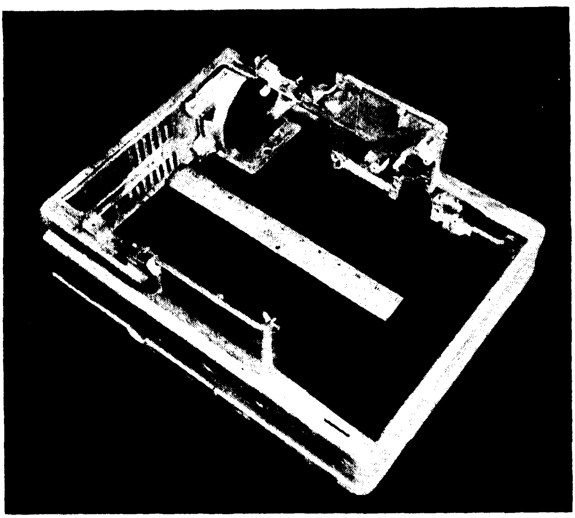


b

FIG. 5.9. *a*. Die-cast aluminum components for a typewriter frame. *b*. The completed frame after assembly by welding.

heat-treatment. Castings can be, and are being, made commercially that will withstand these temperatures, but special precautions are necessary during manufacture.

Sand and permanent-mold castings, as well as plaster-mold and precision-investment castings, are less given to this trouble and can be used at elevated temperatures within the limits imposed by the loss of mechanical properties. The same is true for wrought materials. The permissible temperature range for plastics is considerably lower than for metallic material processed by any of the listed methods. The softening point, that is, the temperature above which mechanical properties drop rapidly, is as low as 100°F in some plastics; in others it may go as high as 300°F. Some of them are readily ignited when exposed to a flame or arc, while others are fire-resistant.

Subnormal temperatures have no injurious effect on aluminum, magnesium, and copper-alloy die castings. Zinc die castings suffer a temporary loss of impact strength at subnormal temperatures (see Chap. 7, Die-casting Alloys). Subnormal temperatures markedly affect the toughness and shock resistance of many steels, cast and wrought, and also plastics.

WELDABILITY

The weldability of a part produced by any given process is a function not so much of the process but of the material from which the part is made. Then, too, the weldability must be considered for a particular type of welding process: arc, gas, resistance, or a variation thereof.

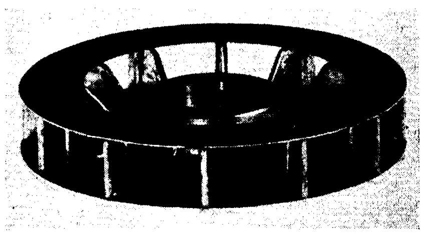


FIG. 5.10. Blower assembly made by riveting a steel plate over a die-cast aluminum bottom plate and blades. More recently, spot welding has been used to make the assembly.

Not much welding of die-cast parts is done, although it is entirely practical for parts cast of aluminum and, to a lesser extent, of magnesium. For example, the components of a typewriter frame and the completed frame assembly, which was made by welding, are shown in Fig. 5.9; this frame previously was bolted together, but welding proved more economical. A somewhat similar case is that of the fan assembly (Fig. 5.10). Some blowers of this type are made by casting the lower plate and blades as a unit; projections are left on the top of the blades which are riveted over the top plate when it is added. More recently, spot welding has been applied to join the steel top plate and the die-cast aluminum body.

Zinc, tin, or lead die castings, of course, are not ordinarily weldable except by the use of special techniques, but they sometimes can be joined by other methods such as brazing or soldering. In this respect, parts

made by some of the other production processes can be considered more adaptable to subsequent welding operations, especially if such parts are made from low-carbon or low-alloy steel.

LEAKAGE RESISTANCE

The resistance to the passage of air, gas, or liquids through the section to the surface in die castings is not materially affected by the presence of porosity as long as the pores are not interconnected and are separated from each other by metal walls that are strong enough to withstand the pressure of the fluid. It is, however, affected by interdentritic shrinkage, which causes interconnected interstices that provide a path from one surface to another. Die castings subject to such porosity can be made leakproof by impregnating them with various types of sealants, such as sodium silicate, polystyrene, and similar synthetic resin materials, usually under pressure. Such impregnating treatments are not too easily applied and are quite expensive, compared with the cost of the castings. However, literally thousands of die-cast parts applied in the plumbing, general hydraulic, pneumatic, and process industries are produced sound enough to obviate the need for any treatment to make them leakproof.

By careful coordination and control of the casting variables, such as metal and die temperatures, pressures, shot speeds, and lubrication, as well as gating and venting, die castings can be made sound and free from porosity. Household gas-meter housings, automotive hydraulic transmission parts, and various types of valves are examples of such sound die castings which do not require any treatment to make them reliable and successful.

When a die-casting job calls for passage of a liquid through the section along a certain well-defined path, a tube made of a material chemically impervious to the liquid can be inserted in the casting. This technique is exceptionally well suited for die castings—more so than for sand or permanent-mold castings.

Sand, permanent-mold, plaster-mold, and precision-investment castings cannot be relied upon to have the same leakage resistance as wrought materials, due to a less compact metal structure; frequently, they also are impregnated, plaster-of-paris and precision-investment castings probably less often than the others. Wrought materials have the greatest pressure resistance. Powder-metal parts have a very low resistance to leakage due to their usually porous structure; as a matter of fact, they are often used for liquid filters or for oil-impregnated sleeve bearings, which are applications that are based on the porosity of sintered powder parts.

TIME REQUIRED TO START PRODUCTION

In die casting, a time lag exists between the design of the die and the casting of the part. This time is required for fabricating the die, trying it out, and determining the best casting conditions to produce the most satisfactory castings.

Permanent-mold castings, although generally requiring less time than die castings to get into production, do require careful and sometimes prolonged periods of production tryout.

Sand castings require less time to get into production than either die or permanent-mold castings. The manufacture of pattern equipment is faster, the tryout period is shorter, and changes in patterns and cores indicated as necessary by the sample run are made faster.

Plaster-mold castings require considerable time for the fabrication of the pattern—only a little less than for die castings, although somewhat more than for permanent-mold castings—but other items like the operating cycle are much simpler to determine. The time required to get into production is generally more than for sand castings, but about the same as for permanent-mold castings.

Precision-investment castings, as a general rule, take about as long as die castings, and so do powder-metal parts. Stampings and drawn parts may require even more time than die castings, especially when intermediate anneals with several sets of dies are necessary. The time required for setting up screw-machine parts is probably less than for any other process if they do not require too many special tools and attachments.

Drop forgings of simple shape can be put into production at a faster rate than die or permanent-mold castings; when they are more complicated and require several successive operations, they may be about as fast as die castings or, in some cases, slower. Die-pressed parts of simple shape may take longer than simple drop forgings. In more complicated shapes, when more than one operation would be required in drop forging, they probably require less time.

COST PER PIECE

The unit cost of a manufactured item covers three things: (1) the cost of producing it, including its share of the tool equipment and overhead cost; (2) the cost of finishing it, including trimming, machining, forming, and plating; and (3) the cost of assembling it into a composite body, unless it is a self-sufficient part. This cost is the final balance of all the individual cost items that have to be considered. In one or more respects,

TABLE 5.2. COMPARISON OF DIE CASTING

Process	Process defined	Materials	Rate of production	Size and weight of parts
Die casting	Castings made by forcing molten metal under external pressure into a metallic die or mold.	Lead, tin, zinc magnesium, aluminum, and copper alloys.	Very high. Up to 500 shots/hr possible with some parts.	No real size limitation. Size depends upon casting equipment available. Present max sizes run: 15 lb for aluminum, 10 lb for magnesium and 30 lb for zinc.
Permanent-mold casting	Castings produced by pouring molten metal under a gravity head into metallic molds.	Iron, magnesium, aluminum, and copper alloys.	Relatively low. Not a high-production process.	Usually medium or large parts. Between die castings and sand castings.
Sand casting	Castings made by pouring molten metal under a gravity head into molds prepared by packing molding sand around a suitable pattern.	Principally iron, magnesium, aluminum, and copper alloys.	Low. Not a high-production process.	Medium to very large.
Plaster-mold casting	Castings made by pouring metal under a gravity head into molds made of gypsum with strengthening and setting agents added.	Any nonferrous material having a melting point of less than 2000°F, except magnesium in large sizes.	Low. Not a high-production process.	Relatively small.
Precision-investment casting	Castings made by pouring molten metal into refractory or ceramic molds formed around wax patterns. Patterns are removed by melting in the process of firing of the refractory.	Iron, zinc, magnesium, and copper alloys and especially high-alloy steels.	Usually lowest of all processes.	Small parts only. Max weight of part about 10 lb, or up to 20 lb by special techniques. Section size usually limited to 7 in. or less.
Powder-metal pressing	Parts made by pressing metal powders in a mold or die to form a "green" briquette of a final shape and "sintering" the briquette to a service strength by a temperature somewhat below the melting point of the lowest melting constituent of the metal.	Mostly copper- and iron-base alloys.	Very high. Up to 1,200 parts/hr on small simple shapes.	Small parts only, except porous filters.
Plastic molding	Nonmetallic organic parts molded by injection or compression under heat and pressure in metallic dies.	Thermoplastic and thermosetting resins.	Very high, especially with thermoplastic resins. About equal to die casting.	Small to medium size.
Stamping and drawing	Parts produced from solid metal by press-forming operations.	Steel, zinc, magnesium, aluminum, and copper alloys.	Very high for small parts made on automatic presses.	From small thin sections to large heavy parts.
Screw-machine production	Parts machined out of solid metal by turning, forming, facing, drilling, or threading on manual or automatic screw machines.	Free-machining compositions of iron, zinc, magnesium, aluminum, and copper alloys.	Very high.	Small parts only.
Drop forging and die pressing	Parts produced by working a billet of hot metal to approximately final form by repeated hammering or pressing while enclosed in a suitable die.	Steel, magnesium, aluminum, and copper alloys.	High.	Small to large.

WITH OTHER PRODUCTION PROCESSES

Strength of parts	Wall thickness	Complexity	Other characteristics
High unit strength.	Very thin; up to 1 in. or more max.	From simple to very complex.	Inserts of almost any metal can be embedded in castings.
High.	Not so thin as die castings, but much heavier sections possible.	Usually not so complex as die castings.	Inserts can be used.
Less than die castings or permanent-mold castings.	Must be heavier than die castings and permanent-mold castings. Can be cast in sections 1 ft or more.	Housings and hubs represent average degree of complexity.	Inserts seldom practical.
Equal to sand castings.	Not as thin as lead, tin, or zinc die castings, but sometimes equal to die castings of aluminum, magnesium, and brass.	Usually not so complex as die castings or permanent-mold castings.	
Equal to or better than permanent-mold castings.	0.040 in. min 1/16 in. prescribed min. Tolerance on walls no less than 0.005 in. min.	Intricate shapes not readily made by machining, forging, or sand casting can be produced.	Min thickness of trailing edge equal to 0.015 in. min and preferably 0.025 in. Inserts not practical.
About equal to plastic parts.	Depends on design; sometimes thinner than die castings. Min about 1/32 in.	Small gears represent about limit of complexity. Almost any shape in direction of press ram movement.	As yet moving die members not commercially feasible. Inserts can be used but not too common.
Less than parts made by most other methods.	Sometimes thinner than die castings, but such sections have little strength. From 1/8 to 5/16 in. preferred max thickness.	Equal to die casting.	Inserts used almost as widely as in die casting. Multiple colors can be molded with one plastic molding on top of another.
Higher than die castings because hot and cold working breaks up cast structure.	From thin gage sheet to plate 1 in. or more in thickness.	Simple shapes only.	Inserts impractical.
Slightly higher than die castings.	Depends entirely on part design and stock used. Thinner than die castings in many instances if part is small.	Relatively complex shapes such as can be turned, drilled, and rolled.	
Highest of all processes.	Must be heavier than die castings.	Fairly complex.	

TABLE 5.2. COMPARISON OF DIE CASTING WITH OTHER PRODUCTION PROCESSES (*Continued*)

Process	Appearance and finish	Cost	Applications
Die casting	Excellent. Can be finished with variety of mechanical, plated, chemical, or organic finishes.	High equipment cost, high tool cost, and low labor cost. Low part cost on high-activity items. Machining, grinding, and other operations usually not necessary.	Structural parts, machine elements, and decorative members and parts for automotive, business machine, electrical appliance, and all other high-production industries making both industrial and consumer products.
Permanent-mold casting	Usually machined or ground but left with base-metal surface.	Medium equipment cost, high tool cost, high labor cost. Fairly high part cost.	For parts similar to sand castings but which must have superior surface finish, closer tolerances, and better strength in as-cast condition.
Sand casting	Inferior to die or permanent-mold castings. Usually machined or ground but left with base-metal surface.	Low tool cost, high equipment cost, high labor cost. Part cost between those of die castings and precision castings.	Gears, framing members, housings, motor blocks, and structural members when cast structure having relatively low strength and resistance to impact is satisfactory. Usually limited to cast iron and cast steel for industrial equipment.
Plaster-mold casting	Excellent.	Low tool cost, low equipment cost, high labor cost, fairly high part cost.	Various engineering parts, mostly of brass alloys.
Precision-investment casting	Equal to die castings, but usually left with base-metal surface.	Low equipment cost, low tooling cost, high labor cost, high part cost.	Small intricate parts made in limited quantities, usually from high-alloy metals such as stainless steel, Inconel, Hastelloy, etc.
Powder-metal pressing	Good but porous. Usually left with base-metal surface. Difficult to plate.	Medium equipment and tooling cost, low labor cost, low unit cost when made in large quantities.	Small mechanical components, electrical parts and filters when low strength and resistance to impact is not detrimental. For parts, like bearings, when impregnation with lubricant is desirable.
Plastic molding	Excellent. Can be molded in variety of colors and with excellent finish.	High equipment and tooling cost, low labor cost, low part cost on high-activity items. Machining, grinding, or subsequent operations usually not necessary.	Structural parts and housings especially in consumer products, toys, novelties. Usually used because of excellent appearance, good thermal and electrical insulating properties, and ability to be welded in complex shapes.
Stamping and drawing	Dependent almost entirely on finish of sheet or plate stock used.	High tooling and equipment cost, low or medium labor cost, low unit cost in large quantities.	Parts that can be punched, pierced, drawn, or formed from sheet metal or plate, especially for parts to be welded or brazed into assemblies.
Screw-machine production	Generally has some tool marks.	High component cost, low tool cost, low labor cost, low unit cost.	Small mechanical elements made from tubing or bar stock, small crank pins, screws, studs, parts for mechanical pencils, watches, etc.
Drop forging and die pressing	Inferior to die castings. Usually left in base-metal state.	High tooling, equipment, and labor costs. Low unit cost on high-activity items.	For medium-sized and large parts that must have very high-impact tensile and compressive strength and excellent mechanical properties in general. Greatest production in ferrous alloys. Shafts, gear blanks, gas turbine impellers, sleeve bearings.

each one of the various processes may excel. One may entail the lowest process labor cost, another may have the lowest tool cost, and another the lowest machining cost. Only by combining them all can the customer find out which process is the most economical for his job.

As a general proposition, the following formula may be used:

$$\text{Unit cost} = \frac{T + N(P + F + M + A)}{N}$$

where T is the total tool cost, P the price per piece quoted by the manufacturer, M the customer's cost of machining the piece, F the customer's cost of finishing the piece, A the customer's cost of fitting the part into a composite assembly, and N the number of parts making up the whole lot.

The piece price P, of course, must be based on a definite schedule of production in order to take care of intermittent setup charges. Some consideration must also be given to the question of whether the original quotation includes a "one-time" charge for tools with no further obligation to the customer as in die castings, or whether upkeep, repairs, and renewals of tools will have to be paid for periodically.

The purchaser should therefore not be prejudiced against a certain process if one of these factors seems to be much higher than it is for another process as long as some of the other factors make up for it. For instance, in die castings the tool cost may be very large, but if the saving in labor cost and cost of machining is considerable and the number of parts ordered is high enough, the final answer to the equation is generally favorable. Obviously, on the other hand, if N is low, M particularly must be quite large to get a favorable end result from the formula.

It should be emphasized that the final choice of the process should not depend solely upon the cost question. Mechanical serviceability, time required for getting into production, appearance, and other factors should be given due consideration.

Table 5.2 is a summary of all the manufacturing and service-performance items treated in detail in the preceding paragraphs. It is difficult to condense the individual characteristics of the several processes in a precise rating, for they vary under certain conditions. The ratings should be looked on as a broad generalization, and more detailed data should be consulted when selection is close.

CHAPTER 6

DIE STEELS

Steel plays an extremely important role in the manufacture of die castings. Upon it rests the responsibility for the development and economical operation of the process, especially for the die casting of metals and alloys having high melting temperatures.

Die-casting dies are, of necessity, expensive, and the thousands of dollars expended in fabricating them must be justified by good serviceable life as measured in terms of the production of an adequate number of castings (Fig. 6.1). To obtain economical life for any die, the steel used in fabricating it must be of a suitable composition and must be prepared under the best possible steel-mill conditions. Other factors such as die design, heat-treatment, and care and handling of the die in production also are very important, and errors in these factors can result in an uneconomical die life even with the best type and quality of die steel.

REQUIRED CHARACTERISTICS OF DIE STEELS

The cover- and ejector-die blocks of the die assembly are exposed to the most severe operating conditions and actually represent the major problem in proper selection of materials. If they are to operate successfully, the steels used in fabricating them should have the following characteristics:

1. Structural soundness and uniformity.
2. Good machinability.
3. High resistance to heat checking.
4. Sufficient strength and hardness to resist deformation in service.
5. Sufficient toughness to resist cleavage cracking.
6. High resistance to the erosive and washing action of the die-casting alloy.
7. High thermal conductivity.
8. Low coefficient of thermal expansion.
9. Dimensional stability in heat-treatment.

Structural Soundness and Uniformity. Since repeated casting of hot metal under high pressures against a die surface will enlarge the most

minor defect to a point where the die is of no value and must be scrapped or repaired, all steel going into the fabrication of die-casting dies must be absolutely uniform, sound, and free from segregated impurities, cracks, seams, scale, and other defects.

Small cracks or flakes that are closed so tight that they are hardly visible to the naked eye will develop into pronounced defects after a few hundred castings are made. Small inclusions of nonmetallic material and

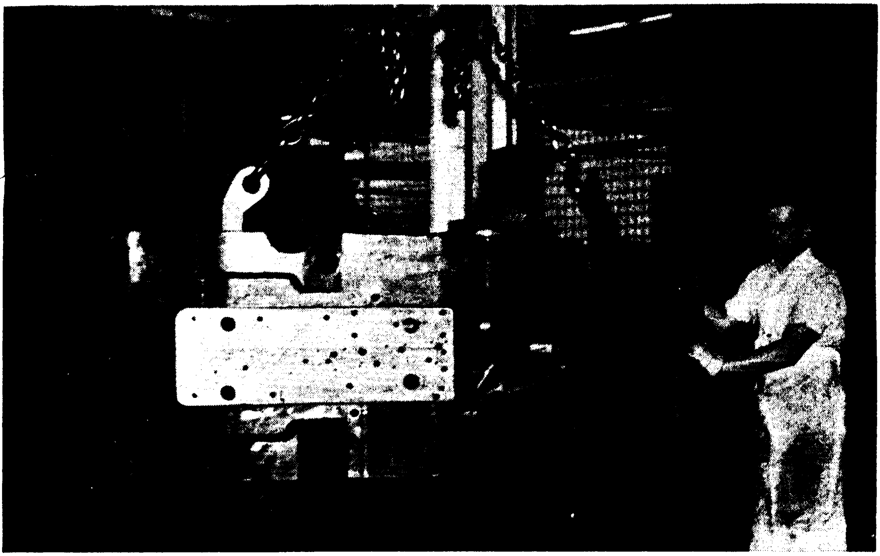


Fig. 6.1. Removing a partially completed die from a duplicating machine. Steel for dies and die components must be of exceptionally high quality—especially for a die of this size—since low part cost depends largely on a long die life.

stringers of microscopic inclusions will be washed from the steel after relatively few castings or cycles, and the resultant cavity will grow to form a major defect. Alloy segregation also has been known to cause surface failure and short die life.

Major defects such as cracks, hammer bursts, seams, and porosity obviously cannot be tolerated on the surface of a die cavity. If these major defects are large, they will weaken the die mechanically even if they do not exist in the die impression.

To minimize the occurrence of such defects, steels used for die-casting dies must be of the highest quality tool steel. Since die cavities that are sunk into a die block usually pass through or terminate at the center of the block where the most defects in forged bars or blocks are located, it is imperative that ample top crop be made on an ingot to ensure

maximum soundness. To ensure maximum refinement and uniformity, the steel must receive an ample reduction in being processed from the ingot to bar or block form and must be processed under proper working conditions and finishing temperatures.

Machinability. The more difficult a die steel is to machine, the greater is the ultimate cost of the die, since the greater percentage of die cost is

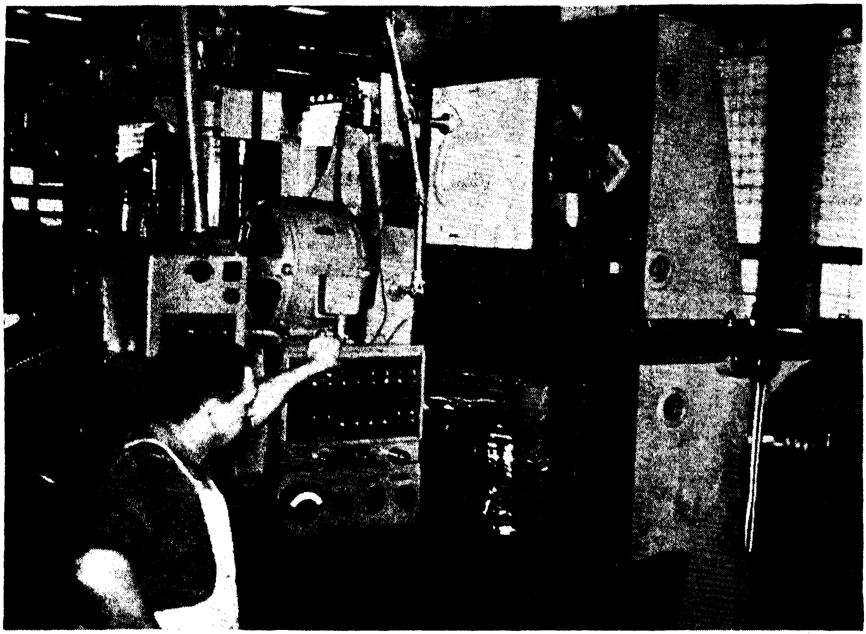


Fig. 6.2. Sinking a die impression with a large duplicating machine. The most practical method of making such dies is to heat-treat them after machining; the steel should be capable of being hardened to between 300 and 450 BHN, depending upon which alloy is to be cast.

in labor. Consequently, die-casting dies usually are fabricated from a fully annealed steel (Fig. 6.2) because a steel in this condition has the desired machinability. The only difficulty to this procedure is that the dies must be given a full heat-treatment when they are finished, and in some cases, especially when the die cavity is large and intricate, full heat-treatment may cause uncontrollable distortion.

For zinc dies, therefore, it may be expedient to use prehardened steel with hardnesses ranging from 200 to 300 BHN. With this type of steel, some sacrifice is made in machinability to obviate heat-treatment after the completion of the die.

Age-hardening steel also may be used for zinc die-casting dies, since they can be readily machined in the solution-treated condition.

Resistance to Heat Checking. The greatest single cause of failure in die-casting dies is heat checking, which is the formation of a network of small cracks on the die surface (Fig. 6.3). The erosion of gun barrels by powder gases is the only type of steel failure that closely resembles the heat checking of die-casting dies, although a similar but much coarser phenomenon occurs on the surface of permanent molds and steel ingot molds.

The cause of heat checking is quite obvious. It results from forcing molten metal under pressure into intimate contact with the die, thus causing the die surface to become very hot in relation to the adjacent metal. Experiments made by the Doehler-Jarvis Corporation and confirmed in a paper by Ernst Michel indicate that the temperature of the die surface closely approaches the temperature of the cast metal. Michel shows that the time required to heat the surface of the die cavity from normal temperature to cast-metal temperature is less than $\frac{1}{1{,}000}$ sec. The actual increase in temperature of the die surface depends upon the type of metal cast and is 300 to 500°F for zinc-base alloys, 600 to 1000°F for aluminum-base alloys, and 1000 to 1400°F for copper-base alloys, depending upon the original temperature of the die.

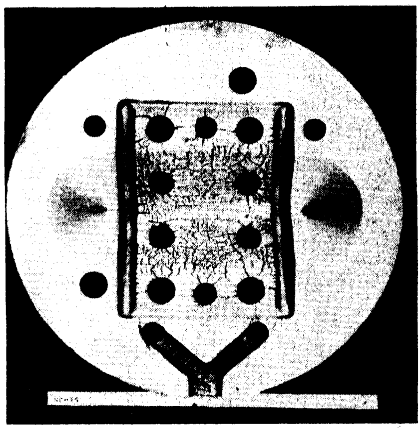
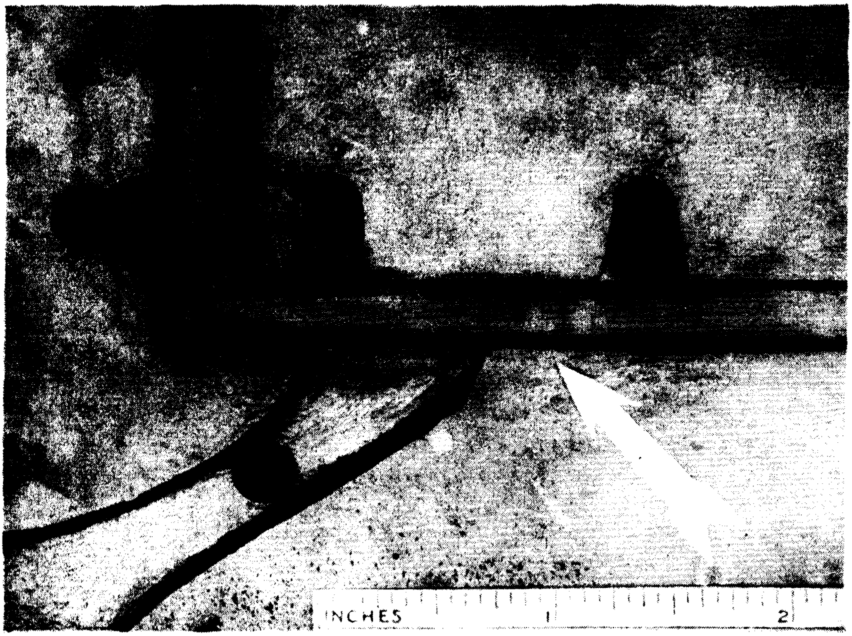
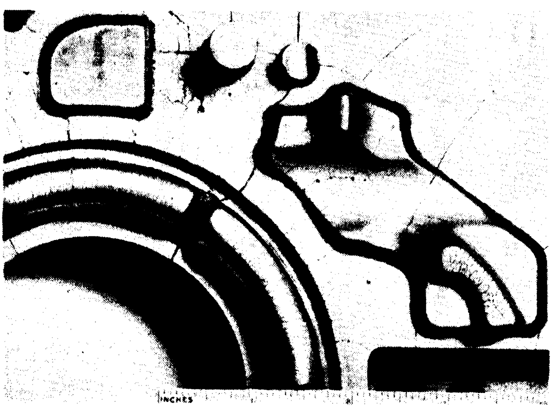


FIG. 6.3. Coarse heat checks on the surface of a die used to cast small brass parts.

This increase in temperature is accompanied by a corresponding thermal expansion, which is about 7.8×10^{-6} in. per in. per °F. When this coefficient of expansion is multiplied by the several hundred degrees of temperature differential between the surface of the die cavity and the inner metal adjacent to it, it is evident that an expansion greater than the elastic deformation that the steel will withstand at these elevated temperatures must take place on the surface. Therefore, there is apparently some plastic deformation on the inner surface of the die. When the heat of the surface is removed by conduction through the die and the surface cools to the normal die temperature, it contracts; and because of the plastic flow that occurred on heating, the surface definitely



a



b

FIG. 6.4. Two degrees of heat checking on dies for casting aluminum: *a*, fine heat checks; *b*, coarse heat checks and cleavage cracks. In both cases the dies had to be replaced.

is in tension on cooling. After a sufficient number of cycles, cracking results, as shown in Fig. 6.4.

Many controversial theories on how to correct these conditions have been advanced, many of which do not appear to have practical application to die casting. As would be expected, the most serious heat-checking problems occur in the casting of alloys of high melting temperature, such as aluminum- and copper-base alloys. Present steels are adequate for casting aluminum since heat checking does not occur until an economical number of castings have been made. In the case of copper-base alloys, however, this is generally not true, and extensive investigations have been carried on for a number of years in an attempt to develop a suitable material for brass die-casting dies.

Undoubtedly, the high-temperature properties of the steel in respect to hardness, impact strength, tensile strength, ductility, and endurance limit control, in part, the tendency toward heat checking. Physical properties such as thermal expansion, thermal conductivity, and allotropic transformation also play an important part in the heat-checking characteristics of a given steel. No laboratory test yet developed, however, gives a true evaluation of the resistance of die steel to heat checking or simulates the results obtained under actual service conditions. The only satisfactory test is a service test run under practical operating conditions, such as testing the material as a die or as a part of a die under regular production conditions. Heat checking can readily be induced on the surface of steel in several ways: by heating to a high temperature and quenching in a cool medium or by rough, dry grinding of the surface. The results of such tests, however, have never correlated closely with actual service results with the same material.

Resistance to Deformation. Die steels must have sufficient hardness and strength to resist the deformation and defacement caused by high closing and casting pressures. When the die is used in production, small bits of flash are left on the faces after the casting cycle. If these are not removed, and if the die is harder than about 375 BHN, these bits of flash will be squeezed to a flake when the die is closed and will cause high local stresses. When the die is much softer than 375 BHN, the bits of flash will brinell into the steel—a condition referred to as *peening*. Excessive peening of a die results in poor closing and therefore requires reconditioning of the closing surfaces. Also, if the flashed metal is adjacent to the edge of the cavity, it may cause a cave-in toward the impression during the casting cycle.

This condition affects the casting dimensionally and causes marking on the surface of the casting. The harder the die material, the less will

be the cave-in effect. (Hardness can be partially compensated for by die design, but this is covered in Chap. 1, Die-casting Dies.)

Dies can be divided into three classes of hardness, depending upon the steels from which they are made. The softest dies, ranging from 85 to

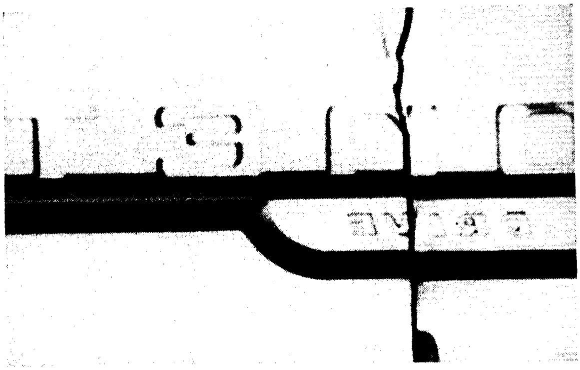


FIG. 6.5. Section of a die that cracked in two pieces. There is another fine crack directly below the letters, but this is not visible.

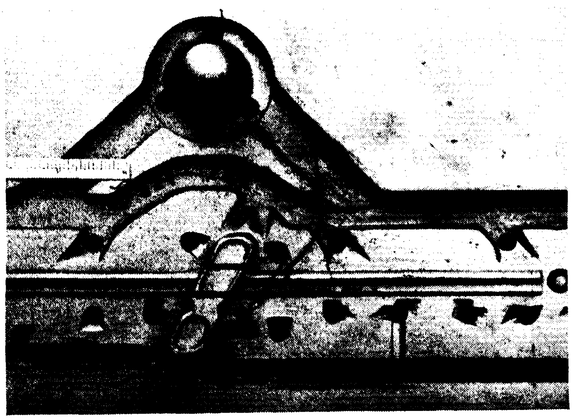


FIG. 6.6. Section of the ejector half of a zinc die that failed by cleavage cracking.

125 BHN, are the hobbed dies made from low-carbon hobbing steel; these dies have very short life, usually failing because of excessive peening and cave-in even though they may be case-hardened. Dies made from prehardened steel ranging in hardness from 200 to 300 BHN have good die life when used to cast low-melting-point alloys of the zinc-base type and when care is taken to keep them well cleaned. The harder heat-treated dies range in hardness from 375 to 460 BHN and include quenched and drawn and precipitation-hardened steels. Use of these steels results

in a minimum of peening and cave-in. The most desirable hardness for quenched and drawn dies is 440 BHN.

Resistance to Cleavage Cracking. Cleavage cracking or fracture of die-casting dies occurs when the die material is stressed beyond its ultimate strength by the formation of high stresses at sharp corners and fillets. These stress concentrations actually cause minute cracks (Fig. 6.4) that may progress to serious fracture (Figs. 6.5 and 6.6). Therefore, every effort must be made to eliminate such points of high stress in the die design and to select a die steel that has the ability of distributing stresses.

The ability of a steel to absorb stress is a function of its toughness, as measured by ductility, reduction of area, impact strength, and notch sensitivity. Generally speaking, the toughness of a steel is inversely proportional to the hardness, and since the service life of a die in respect to heat checking and deformation is dependent upon high hardness, the toughness of the steel must necessarily be a compromise. Experience has shown that steel for die-casting dies should have an elongation of about 10 per cent in 2 in. and a reduction of area of about 40 per cent. No such concrete data are available for impact strength and notch sensitivity.

TABLE 6.1. NOTCH-IMPACT STRENGTH OF DIE STEEL FOR CASTING ALUMINUM*, †

Testing temperature, °F	Longitudinal impact strength, ft-lb	Transverse impact strength, ft-lb
32	2.5	2.6
83	3.2	2.9
212	5.7	4.3
400	7.4	8.3
600	13.4	11.6

* Figures given for impact strengths are the average of several tests on specimens from 2- by 12-in. forged bars drawn to an average hardness of 444 BHN.

† Steel composition, per cent: carbon, 0.37 to 0.42; silicon, 0.85 to 1.00; manganese, 0.20 to 0.50; chromium, 5.00 to 5.50; vanadium, 0.90 to 1.10; and molybdenum, 1.00 to 1.25.

Unfortunately, the steels in use today have very low notch-impact properties as tested by the standard Charpy V-notch test. This is shown by the test values obtained on a standard die steel used for aluminum die-casting dies, as given in Table 6.1. For this test, the notch speci-

mens were taken from midway between the center and the surface of the forged bars. The values shown would have been much higher had the test specimen been forged approximately to size, which is usually done when checking the impact properties of a steel; but since steel for die-casting dies is forged and used in large sizes, the only true test values are those observed on specimens cut from large bars or blocks.

Besides giving an indication of the low notch-impact strength of die steels, Table 6.1 shows another important fact: That the impact properties of these steels increase materially as their temperature is increased. A die at 400°F has about twice the impact strength of a die at room temperature. This demonstrates clearly another good reason for adequately heating dies before putting them in service.

The only other precaution that can be taken to minimize cleavage cracking is to minimize stress concentrations by conservative die design; this point is more fully explained in Chap. 1, Die-casting Dies. Suffice it to say at this point that fillet radii have a considerable effect on the notch-impact strength of these steels, as demonstrated by the values shown in Table 6.2.

TABLE 6.2. EFFECT OF NOTCH RADIUS ON NOTCH-IMPACT PROPERTIES OF DIE STEEL *

Radius at base of notch	Direction of test	Brinell hardness	Impact strength, ft-lb		
			Lowest	Highest	Average
0.000	Transverse	437	3.0	4.0	3.6
0.000	Longitudinal	441	3.0	6.0	3.8
0.010	Transverse	419	5.5	7.0	6.3
0.010	Longitudinal	455	6.5	7.0	6.8
0.020	Transverse	418	8.0	11.0	9.3
0.020	Longitudinal	443	9.0	24.0	16.0
0.040	Transverse	460	9.0	23.0	14.2
0.040	Longitudinal	419	15.0	21.5	19.0
0.080	Transverse	460	14.0	25.0	19.7
0.080	Longitudinal	422	18.0	26.0	21.6
0.125	Transverse	441	19.0	27.0	22.4
0.125	Longitudinal	413	25.0	29.0	26.5

* Composition, per cent: carbon, 0.37 to 0.42; silicon, 0.85 to 1.00; manganese, 0.20 to 0.50; chromium, 5.0 to 5.5; vanadium, 0.9 to 1.10; molybdenum, 1.00 to 1.25.
Heat-treatment: air-quenched in box from 1825°F, drawn at 1065°F.

Resistance to Erosive or Solvent Action of Casting Alloy. The high velocity of the molten die-casting alloy as it enters the die has a tendency to erode or wash metal off the die surfaces (Figs. 6.7 and 6.8). The amount, degree, and frequency of metal "wash" is largely the result of

FIG. 6.7. Three impressions of a six-impression die showing metal wash directly opposite the gate.

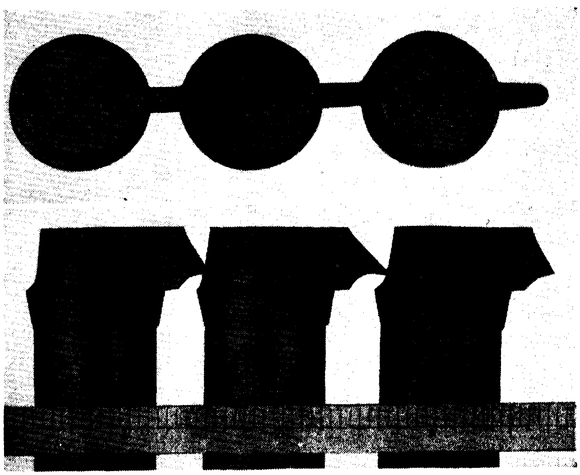


FIG. 6.8. Side and end views of cores that show metal wash. These cores were originally round.

gate design, but past experience has shown that the die steel also is a governing factor since some alloy compositions are more susceptible to erosion than others. For example, production data have shown that increasing the vanadium content from 0 to 1.00 per cent in a 5.0 per cent chromium–1.0 per cent molybdenum steel increases its resistance to metal wash.

However, no experimental tests have been devised for determining the resistance to erosion of die steels. The best present source of information is production data. Since this type of failure is usually confined to a rather small area in a die, it can be overcome by the use of inserts when permissible. Of course, the washed-out area often can be repaired by filling it in with weld metal.

High Thermal Conductivity. The rate of production that can be attained in die casting depends largely upon the thermal conductivity of the material from which the die is made. The thermal conductivity of the die material determines to a large extent the length of time a casting must be held in the die to solidify the metal and the frequency at which successive castings can be made without the die cavity becoming too hot. There are some indications that the thermal conductivity of the die steel also has some influence on the degree of heat checking, but this has not been proved; it is believed that the rate of heat input on the surface of the die is so rapid that, to prevent a steep temperature gradient from the die surface to a fraction of an inch below the surface, the thermal conductivity would have to be increased several times to be effective.

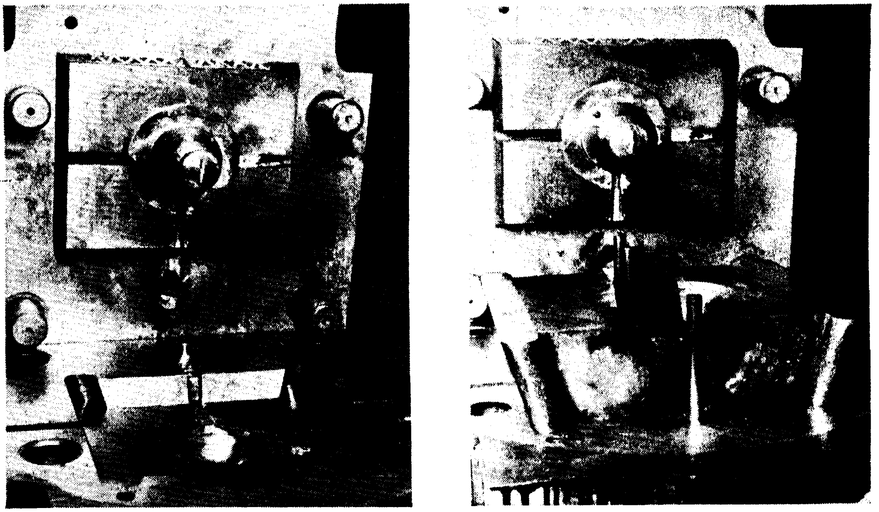
A common proposal is that refractories be used for die-casting dies to overcome the heat-checking characteristics of metals. Most refractories have less than one-tenth the thermal conductivity of steel, which is about 0.1 cal/sq cm/cm/°C/sec at the operating temperature. On the basis of conductivity, molybdenum should be a good die material since it has about three times the thermal conductivity of steel at room temperature, but because of other factors such is not the case.

Thermal Expansion. At operating temperatures of the die-casting die, variations in alloy composition do not effectively alter the thermal expansion of die steel. However, austenitic steels have generally greater thermal expansion than ferritic steels. Therefore, if sufficient alloy is added to make the die steel austenitic at operating temperatures a significant increase in thermal expansion occurs.

A die steel of lower thermal expansion would be desirable as it would probably decrease heat checking and would decrease the change in die dimensions as operating temperature of the die changes. In addition, various components of the die operate at different temperatures (Fig. 6.9). This temperature variation results in a size change depending on the thermal-expansion characteristics of the steel, and in the case of slides and pull cores the higher the thermal expansion the greater would be the tendency for them to stick or gall.

Stability during Heat-treatment. Since many dies must be made with heavy and thin sections adjacent to one another, it is apparent that the heat-treating characteristics of the die steel are critical. Unlike other heat-

treated tools, many die-casting dies are completely machined, ground, and polished prior to heat-treatment. Distortion or changes during heat-treatment cannot be corrected by finish grinding since there is no excess stock that can be removed. Therefore, the die material should be so selected that it can be heat-treated to the proper hardness without excessive warpage, growth, or shrinkage; without carburization or decarburization; and without the formation of oxides, pits, scabs, or checks.



Closed Open

Fig. 6.9. Angular-ejection die. Thermal expansion of the steel should be low to minimize seizure and galling of the moving parts.

Any warpage of the die during heat-treating may render it useless or at least necessitate costly reworking so that it can be fitted to its mating part. To minimize warpage and dimensional changes, an air-hardening die steel should be used whenever possible. Moreover, the steel should be so made and heat-treated that it has a constant size change on heat-treatment. Under such circumstances, even though the change is appreciable, it can be compensated for in the design of the die.

The die steel also should be of such composition that a martensitic structure is obtained throughout on quenching. The formation of high-temperature-transformation products is undesirable, although some will always be formed, the amount depending upon the steel and the size of section quenched. Some steels have a tendency to crack on heat-treatment because of the high stresses formed during transformation at low temperatures. Steels of this type cannot be used for dies because they are too hazardous to heat-treat.

Finally, the steel should not lose or pick up carbon, nitrogen, or other elements during heat-treatment or the die surface will be damaged; nor should it oxidize and form pits, scale, or scabs. Although there are many methods of controlling the heat-treating atmosphere to protect the surface, these methods vary with the type of steel used and the hardening temperature. Under any heat-treating conditions, some scale will be formed, but it must of necessity be light and uniform; it usually is loosened by immersing the steel in an electrolytic pickling bath, followed by vapor blasting and hand polishing.

QUALITY CONTROL OF DIE STEELS

From the discussion in the previous section it is apparent that every precaution should be taken to ensure that the steel for die-casting dies is of the highest quality and free from defects, especially in the area where the die cavity will be located. The steel should be purchased under a rigid set of specifications drawn up by the metallurgical department and inspected on receipt by macroetch examination; ultrasonic testing; and, in some cases, microscopic examination. Perhaps the clearest way to illustrate good quality-control procedure is to cite one method of purchasing die steel.

Purchase Specifications. Die steels for die-casting aluminum and magnesium must be of an especially high grade because of the high melting points of these alloys. One of these types that is often used has a nominal composition of 0.40 per cent carbon, 0.40 per cent manganese, 1.00 per cent silicon, 5.25 per cent chromium, 1.00 per cent molybdenum, and 1.00 per cent vanadium. This steel is purchased as forged bars when the cross-sectional area is less than about 30 sq in. and as upset forged blocks when the cross-sectional area exceeds 30 sq in. The essential points in the specification are as follows:

1. The steel is to be melted by the basic electric-furnace process and cast into "hot-top" ingot molds designed to prevent secondary pipe.

2. Bars are to be forged by the single-end forging process with a minimum specified top ingot crop of 20 per cent, not including the hot top, and a minimum forging reduction of 10:1.

3. Blocks are to be forged by the upset forge process with a minimum of 50 per cent upset (Fig. 6.10). The stock is to be cut from a billet that has had a forging reduction of 2:1 and a top crop of at least 20 per cent, not including the hot top.

4. The steel is to be cooled slowly from forging temperature to room

temperature and then given a full anneal to a maximum hardness of 217 BHN.

5. The chemical composition is to be within the following limits:

	Per cent
Carbon	0.37 to 0.42
Silicon	0.85 to 1.10
Manganese	0.20 to 0.50
Chromium	5.00 to 5.50
Vanadium	0.90 to 1.10
Molybdenum	1.00 to 1.25
Sulfur	Not over 0.03
Phosphorus	Not over 0.03

FIG. 6.10. Upset-forging a block for a die-casting die.

6. The finished bars are to be macroetched on both ends to check freedom from segregation, nonmetallic inclusions, cracks, hammer bursts, corner cracks, internal ruptures, seams, and other injurious defects or

impurities. These macroetches are to be shipped to the purchaser for examination.

7. The top end of the billets used for forging-block stock is to be macroetched to show freedom from the previously mentioned defects and then shipped to the purchaser for inspection.

8. The steel is to have a fine grain and be relatively free from microscopic inclusions or groups of such inclusions.

9. Bars and blocks are to have a workmanlike finish and are to be marked as requested by the purchaser.

Fig. 6.11. Chemical laboratory of a large die-casting plant. A periodic check of die-steel composition is necessary to ensure uniformity.

Chemical Composition. All die steels purchased for impression dies are purchased to rigid chemical specifications just as the alloy steel previously described, and the supplier must submit the heat analysis of each steel shipped. Periodically the chemical composition of the steel is checked in the purchaser's laboratory (Fig. 6.11). Obtaining the exact composition specified is not so important as obtaining the same composition at all times. When the steel is purchased from more than one supplier, the composition from each supplier should be the same. Variation in composition will cause changes in heat-treating characteristics, and thus will not permit standardization of heat-treating practice.

Macroetch Inspection. Each die steel, regardless of type, is given a 100 per cent macroetch inspection. Both ends of the bars are macroetched, and the top end of the billets from which the forging stock is

cut are also macroetched. Generally, these macroetches are supplied by the producer. Among the defects that are determinable by macroetching are porosity, segregation, cracks, flakes, hammer bursts, seams, and nonmetallic inclusions.

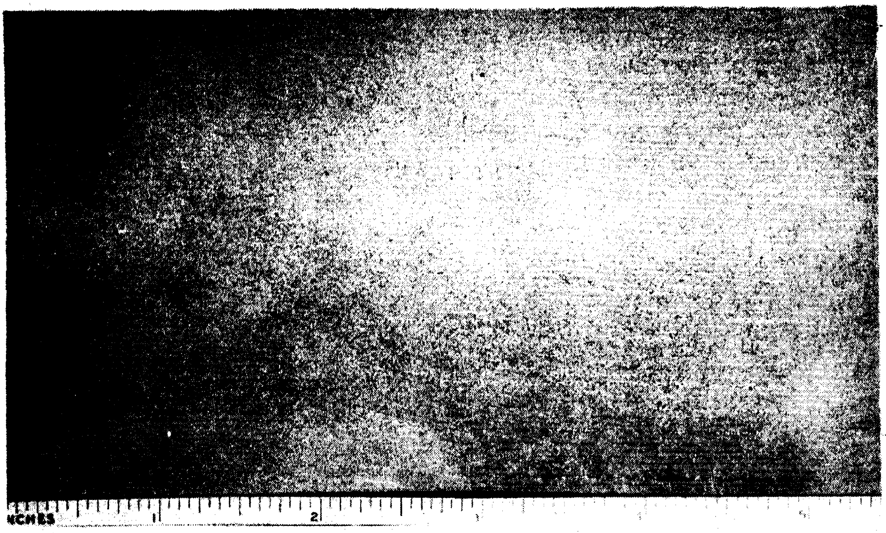
The macroetch test consists of immersing a ground, cross-sectional plate of a bar or billet in hot 50 per cent hydrochloric acid for from 30

FIG. 6.12. Macroetched sections from 3- by 10-in. forged bars of die steel. The top bar shows the desired structure; the bottom bar shows some segregation and center porosity.

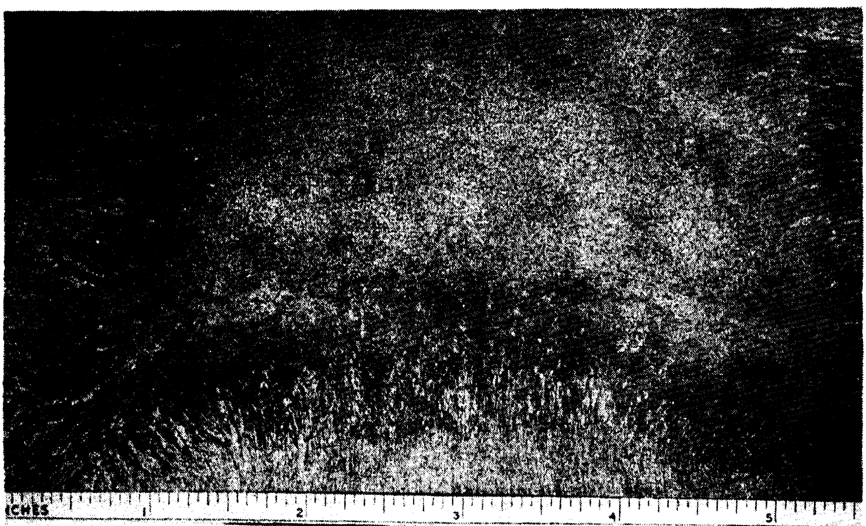
to 90 min. The time of the etch depends upon the temperature of the acid and the composition of the steel; sufficient etch must be obtained to show the structure of the steel, or the defects may be overlooked.

Macroetch photographs of two 3- by 10-in. bars are shown in Fig. 6.12. The upper bar has the uniform structure desired, while the lower bar shows segregation and slight center porosity. The uniformity of the lower bar would be considered good for most other applications, but for die casting it is undesirable.

Macroetches of two 6-in.-square billets from which forged-block stock is taken are shown in Fig. 6.13. The billet shown at *a* has the desired



a



b

FIG. 6.13. Macroetched sections from a 6- by 6-in. billet from which an upset-forged die block was taken. The section at *b* shows center porosity and ingot pattern; that at *a* a uniform structure.

uniform structure, while that at *b* has center porosity and ingot pattern. The center porosity in this billet is particularly undesirable. The ingot pattern shown is not too detrimental, but when much coarser than this should not be allowed. The light-colored columnar crystals around the edge of billet *b* have no effect on the quality of the steel, since they will be broken up during the upset forging operation.

Segregation becomes a serious problem on large die blocks, which are necessarily made from large billets. A sound, uniform 16- by 16-in.

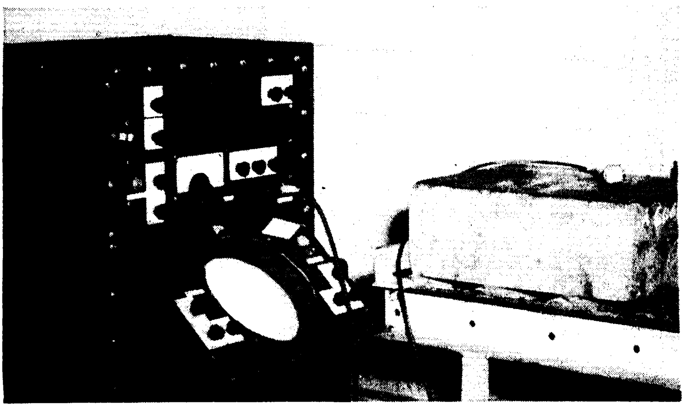


FIG. 6.14. The supersonic Reflectoscope is invaluable for checking the internal soundness of die blocks, *i.e.*, absence of small cracks, flakes, nonmetallic inclusions, or localized porosity.

billet is difficult to make, for the high-alloy steels needed for die-casting dies segregate when cast into large ingots. Not much can be done to minimize this except to use as small an ingot as possible to make the desired forged bars or die blocks.

Ultrasonic Inspection. Although die steels may have the proper chemical composition and show a satisfactory structure as determined by macroetching, they still may have internal defects in restricted areas. If these small internal defects are not detected until the die is completed, it may have to be scrapped; therefore, it is standard practice to check the soundness of the material by ultrasonic inspection.

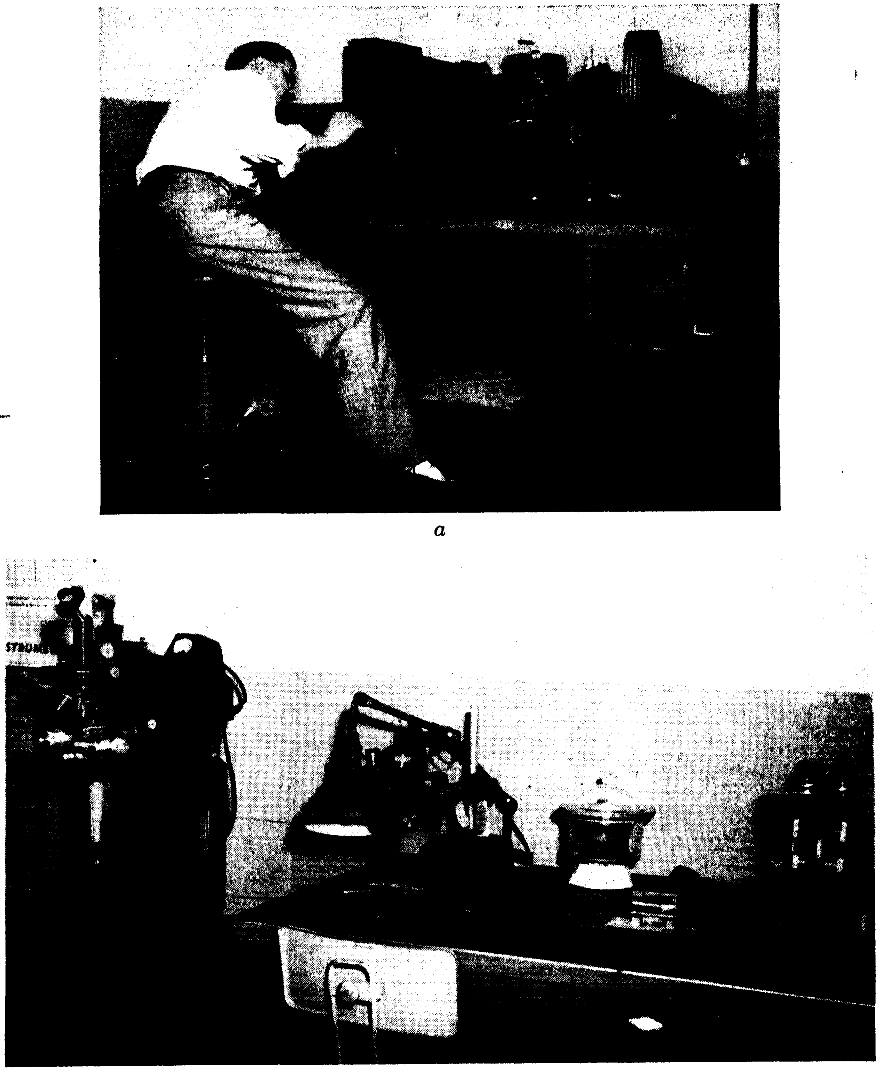
Ultrasonic testing consists of introducing a high-frequency sound wave into the steel and measuring the length of time required for it to be reflected back to the point at which it was introduced. Commercial instruments are available for this type of testing, one of which is the Sperry Reflectoscope (Fig. 6.14). The time intervals can be measured simply and accurately with an oscilloscope.

When a high-frequency wave is introduced into the side or end of a steel block that is free from defects, the wave is reflected from the back side. If there are defects in the path of the wave, it will be reflected from the defect—either back to its source or to another part of the section. Therefore, if a reflection occurs earlier than the normal back reflection, or if the back reflection is completely or partially lost, a defect exists below the point at which the wave is introduced. As the area over which the wave is introduced is usually 1 sq in., it is possible to locate a defect accurately. Also, the accuracy of the time measurement made with an oscilloscope is such that the depth of the defect can be determined to within about ¼ to ½ in.

The type and size of defect which can be detected by ultrasonic inspection depends upon the wave frequency used, the sensitivity of the instrument, and the skill of the operator. Under proper conditions, coarse grain boundaries and segregation can be indicated. However, most of the defects consist of small cracks, flakes, relatively large nonmetallic inclusions, and localized porosity or segregation. Large hammer burst or internal ruptures also can be located, but such defects occur infrequently.

Ultrasonic inspection usually is used to test all die steels, large slides, and cores. Whenever possible, all blocks are checked for defects in three directions, for otherwise, if the defect were parallel to the direction of testing, it might be overlooked. An ultrasonic wave frequency of 2¼ megacycles is used on all first testing, and frequencies of 1 or 5 megacycles are resorted to when additional data are desirable on a probably defective steel. The sensitivity of the instrument is set by using a standard block of sound steel in which an artificial defect has been made. The artificial defect consists of an 0.020-in.-diameter hole drilled ½ in. deep at right angles to the direction of testing, or an 0.0625-in.-diameter, flat-bottom hole drilled into the back of the test block parallel to the direction of testing. Both of these artificial defects give about the same intensity of reflection when viewed on the oscilloscope.

As a result of Reflectoscope inspection, die steel is divided into three classes: (1) Steel that has no detectable defects; this includes most of the steel tested. (2) Steel that has a few small defects that can be removed during the making of the die or that are remote from the die cavity. This group is the second largest classification, but still much smaller than the first group. (3) Steel that has a few defects which are located in a critical area, numerous small defects, or a major defect, such as a hammer burst or an internal rupture. Steels in this third group are rejected and not used for the manufacture of die-casting dies.



a

b

FIG. 6.15. Microscopic equipment in a modern die-casting plant. Microscopic inspection of die steels shows grain size and the presence of nonmetallic inclusions. *a*, Photomicroscopic equipment; *b*, Tukon superficial hardness tester and auxiliary microscopic equipment.

Microscopic Inspection. Die steels should show a minimum of scattered inclusions and have a fine grain size when polished, etched, and viewed under a microscope (Fig. 6.15). No steel having stringers or inclusions or groups of inclusions should be used for impression steels. It is not necessary to check the cleanliness of each billet or bar, however, since periodic checks are satisfactory as long as the supplier maintains rigid melting and casting controls.

SELECTION OF STEELS FOR DIE-CASTING DIES

In the early days of die casting, dies for tin-, lead-, and zinc-base alloys were made from low- or medium-carbon unhardened machine steels. These dies performed satisfactorily since the casting machines then in use were operated at low pressure and at a relatively low production rate.

With the advent of higher melting point alloys, starting with aluminum, ordinary carbon steels for dies became unsatisfactory. Die life was extremely short. It was soon found that only alloy-steel compositions were practicable and, further, that such alloy steels had to be given a suitable heat-treatment to ensure an economical die life.

The first alloy steel used for aluminum dies was an oil-quenched chromium-vanadium steel having the nominal composition of 0.40 per cent carbon, 2.00 per cent chromium, and 0.25 per cent vanadium. Although this steel gave much better performance than carbon steel, it was capable of only about 15,000 casting cycles before replacement became necessary; furthermore, heat-treatment always resulted in considerable warpage and dimensional change. Then followed tungsten-chromium and chromium-molybdenum air-hardening steels, which gave much better results. Although variations of the latter types are still in use today, a continuous search for better die steels has since been in progress, especially to keep abreast with and accommodate the advances made in the die-casting process.

Composition of Present-day Die Steels. One of the major factors governing the selection of a die steel is the die part for which it is to be used: holder blocks for the casting impressions, casting impressions, slides, cores, or ejector pins (Fig. 6.16). Consideration also must be given to the type of alloy to be die-cast and the production expected from the die. The entire problem is one of economics—the selection of a steel that will give the greatest number of casting cycles per dollar invested in material, fabrication, and heat-treatment.

Typical compositions of some of the commercial steels available for die-casting dies are given in Table 6.3.

Die Steels for Zinc Impressions. When die casting started, zinc dies were made from common boiler plate steel and gave rather good life. The casting temperature of zinc, about 800°F, is not high enough to cause rapid heat checking, but with the high pressures and high production of present-day zinc die casting, an alloy steel is necessary. The high closing pressures needed to make possible the use of high casting pressures cause

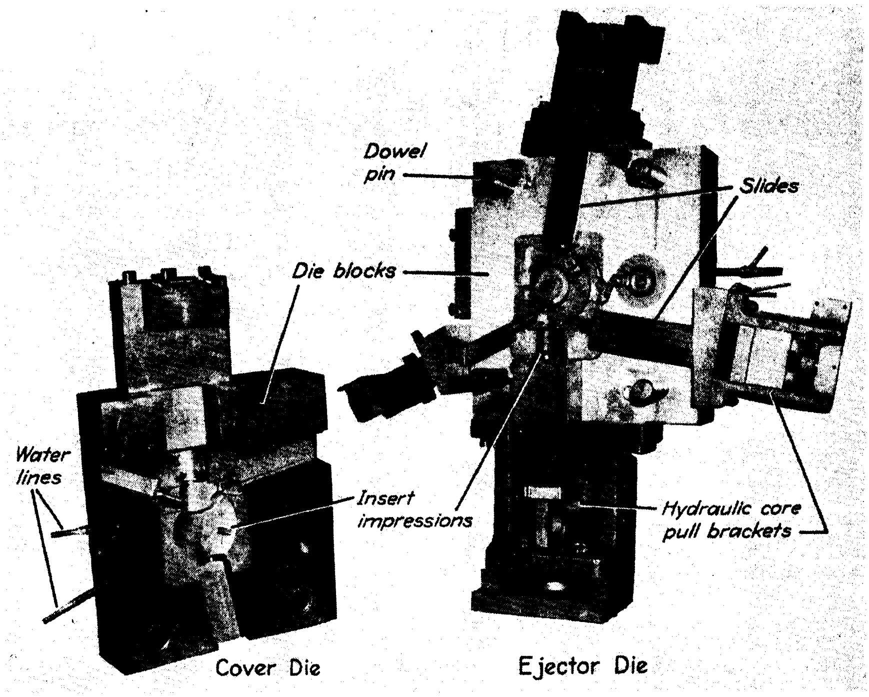


FIG. 6.16. Cover and ejector die for producing an aluminum machine part. Different steels are used for the different components, as shown in Table 6.3.

a soft die to deform or cave in at the edges. High-production dies with slides and close tolerances also require hard dies.

When a hard die (380 to 420 BHN) is required because of design or high production, it is necessary to heat-treat the die after machining, and therefore a nondeforming air-hardening steel must be used. For this application any of the aluminum die steels will be satisfactory. Steel No. 4 (Table 6.3) is satisfactory.

When a softer steel can be used (about 300 BHN) the die can be machined in the hardened state. For this purpose, an oil-hardening steel is used with sufficient alloy added to obtain the desired hardness through-

out the die block. In the selection of alloys, consideration should be given to machinability in the quenched and drawn condition. A chromium-molybdenum steel of the following composition can, in general, be recommended: 0.30 per cent carbon, 0.75 per cent manganese, 0.50 per cent silicon, 0.80 per cent chromium, and 0.30 per cent molybdenum.

TABLE 6.3. COMPOSITION OF STEELS FOR DIE-CASTING DIES *

Steel No.	Composition, per cent								Uses
	C	Mn	Si	Cr	Mo	V	W	Others	
1	0.30	0.30	0.45	3.25	....	0.50	9.00	....	Brass impressions
2	0.30	0.30	0.50	1.40	0.40	....	4.0	5.0 Co	Brass impressions
3	0.40	0.30	1.00	5.00	1.00	0.50	....	....	Aluminum impressions
4	0.40	0.40	1.00	5.25	1.00	1.00	....	....	Aluminum impressions
5	0.35	0.40	1.00	5.0	1.5	0.30	1.25	....	Aluminum impressions
6	0.40	0.30	1.00	5.0	....	....	5.0	....	Aluminum impressions
7	0.30	0.75	0.50	0.80	0.30	....	....	....	Zinc impressions
8	0.05	0.15	....	.....	....	....	....	....	Hobbed impressions
9	0.10	0.20	....	0.60	....	....	....	1.25 Ni	Hobbed impressions
10	0.65	0.30	0.40	17.00	....	....	....	....	Small cores and ejector pins
11	0.35	0.50	0.75	1.25	0.20	....	....	1.25 Al	Small cores and ejector pins
12	0.40	0.70	0.25	0.90	0.25	....	....	....	Holding blocks
13	0.45	0.70	0.25	.....	....	....	....	....	Holding blocks
14	0.40	0.80	0.50	0.80	0.30	....	....	1.00 Ni	Cast holding blocks

* The compositions given are type compositions only since actual compositions vary with manufacturers. Also, other elements than those indicated may be added.

Die Steels for Aluminum and Magnesium Impressions. Before the advent of the present highly alloyed steel, the useful life of an aluminum die was not much longer than the present brass die (10,000 to 50,000 shots). Now there are a number of alloy-steel dies that have made as many as 600,000 shots. The average useful life of a die for aluminum, however, is from 50,000 to 250,000 shots, depending upon the type of casting.

The composition of the various aluminum die-casting die steels is similar in many respects. Most of them contain 0.35 to 0.40 per cent carbon, 0.20 to 0.50 per cent manganese, 0.90 to 1.10 per cent silicon, and 5.00 to 5.25 per cent chromium. The variable elements are molybdenum, which is about 1.0 per cent in most steels, and vanadium, which varies from 0.35 to 1.00 per cent. One popular steel is No. 4 (Table 6.3), which contains 1.0 per cent vanadium to decrease wash at the gate. Other types of steel contain tungsten, about 1.25 per cent being used if molybdenum and vanadium are present, and about 5.0 per cent if no molybdenum or vanadium is present.

All these steels are air-hardening and nondeforming steels, which makes it possible to heat-treat a finished die impression. It is desirable to use these steels as hard as possible to obtain maximum resistance to heat checking, but on the other hand, if the die is too hard, it is susceptible to cleavage cracking. Therefore, it is necessary to compromise on a hardness of about 420 to 440 BHN.

Brass Die Steels. Since about 1930, when brass die castings first came into being, attention has been directed toward the finding of a die material that will yield a serviceable and economic die life.

The fact that such a die material has not as yet been found has been the sole restricting influence in the die casting of metals and alloys having melting temperatures above those of aluminum and magnesium. Brass die castings can be produced with almost the same facility as those of the lower melting point alloys now being die-cast; but because of the higher casting temperatures of brass and other copper-base alloys, their dies have a much shorter serviceable life than dies for the lower-melting-point metals. The die steels used for the die casting of aluminum and magnesium alloys, with casting temperatures of up to 1300°F, are definitely unsuited for brass alloys, whose casting temperatures are about 1700°F.

During the brass die-casting operation, the extreme surface of a die may reach temperatures well above the transformation range of steels. Continued heating of the surface decreases hardness and strength, lowers the resistance of the steel to the erosive action of the molten alloy, and generally nullifies the effect of any previous heat-treatment. During the die-casting cycle, the temperature gradients at the die surfaces are very steep, ranging from the casting temperature of 1700 to 1750°F down to temperatures of 1100 to 1300°F at only about 0.050 in. beneath the die surface. As a result of these thermal gradients, large stresses are set up that cause early die failure.

Hundreds of alloys have been tested to determine their resistance to heat checking when die-casting brass. Although no alloy yet tested has the desired properties, a hot-work steel was selected and has been used for a number of years. This hot-work steel (No. 1, Table 6.3) has approximately the following composition: 0.30 per cent carbon, 0.30 per cent manganese, 0.45 per cent silicon, 3.25 per cent chromium, 0.50 per cent vanadium, and 9.00 per cent tungsten. Another hot-work steel containing 0.30 per cent carbon, 0.30 per cent manganese, 0.50 per cent silicon, 1.40 per cent chromium, 0.40 per cent molybdenum, 4.0 per cent tungsten, and 5.0 per cent cobalt is being used in the industry with a fair degree of success.

The steel suppliers and the die-casting companies are always developing and testing new compositions in the hope of finding a new and better

brass die-casting die material, and there is a definite indication that soon a steel or similar material may be developed that is better than the present hot-work steels.

Steel for Hobbed Die Impressions. Many dies can be made more economically by hobbing the cavity into a piece of soft steel than by machining it into a die block. Of course, there are many die impressions that are not applicable to hobbing, and the size is limited by the capacity of the hobbing press that is available (Fig. 6.17). The largest hobbing presses in common use are 5,000 tons, but these have been known to be loaded to as high as 8,000 tons. The size of the cavity that can be hobbed using 8,000 tons pressure depends largely upon the depth of impression, the detail required, the type of steel being hobbed, and the number of annealing and hobbing cycles that are economical for the particular job.

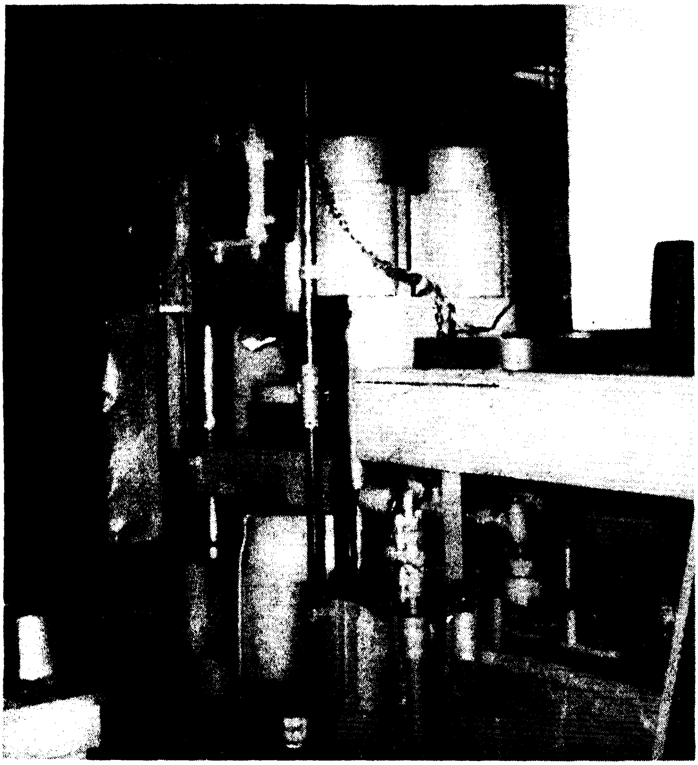


FIG. 6.17. Large hydraulic hobbing press.

A rough estimate of what sizes can be hobbed is indicated by the fact

that it requires about 100,000 psi of hob cross section to hob soft steel. This indicates that a hobbed cavity can be made up to about 160 sq in. Where fine raised detail is required, this size should probably be reduced to 80 sq in.

The normal hobbing steels, containing from 0.05 to 0.10 per cent carbon and 0.15 to 0.30 per cent manganese, with or without 0.40 to 0.75 per cent chromium and 1.00 to 1.50 per cent nickel, are soft steels with an annealed hardness of under 100 BHN. Their use in die-casting dies is limited, even though the surface of the die cavity is carburized and heat-treated. The service life of these steels depends largely upon the shape of the cavity, but they are practical only for die-casting zinc. The common failure of this type of die is cave-in.

The steel from which the hob is made varies with almost every plant that does hobbing. Successful hobs have been made from carbon tool steel, chisel steel, and high carbon-high chromium abrasion-resistant steel. The type specified depends largely upon the pressure required to make the hobbed impressions and on the number of impressions. The major requirement is that the hob be hardened to a hardness of 58 Rockwell C or higher.

Steels for Cores and Ejector Pins. Movable cores and ejector pins must have a very hard wearing surface. This hard surface is necessary to keep galling at a minimum, because cores and pins are difficult to lubricate properly. A hard surface is often obtained by cyanide bath or gas nitriding. Therefore, one requirement of a steel for pins is that it can be nitrided; Nitralloy steel—gas nitrided—is used by a number of die-casting companies for ejector pins.

For small cores of the fixed and pull types, common practice is to use a stainless steel containing about 0.65 per cent carbon, 0.30 per cent manganese, 0.40 per cent silicon, and 17 per cent chromium. An aluminum impression steel, such as No. 3 (Table 6.3), is also being used. Both of these steels are satisfactory for small ejector pins as well.

Small cores are a continuous source of trouble, however. Since the business portions of these cores are entirely surrounded by metal, they become very hot and are subjected to transverse stresses as a result of contraction of the die casting on cooling. The result is a bent pin if the steel is too soft or a broken pin if the steel is too hard. In the case of aluminum, the working temperature of the pin is sufficiently high to cause decreasing core hardness. Steels that have less tendency to be drawn to a lower hardness by the working temperature are being investigated for this use.

Steel for Holding Blocks. The practice of making die impressions of a high-alloy tool steel and inserting these impressions into a large block

of lower cost steel is often found more practical and economical than sinking the impressions in a solid die. The steel block used to hold the impressions is referred to as the *holding block*.

Since the mating surfaces of these holding blocks must be smooth, so that the die seals properly on closing and so that there is no undue wear of cores and other moving parts, one of the salient characteristics required in the steel is that it be hard and resistant to peening and nicking. Also it must have sufficient strength and rigidity to resist deformation and to maintain alignment of the inserted impressions.

The usual method of obtaining a hard holding block is by heat-treating it after it has been machined. This necessitates the use of a nondeforming air-hardening steel; but even with such a steel, large blocks often distort and must be reworked. A more economical practice is to use a lower cost steel, heat-treated before machining. For this purpose, a modified SAE 4140 steel (steel No. 12, Table 6.3), which is prehardened by an oil quench and drawn to 250 BHN, is satisfactory. This steel has sufficient rigidity to hold alignment and does not roughen excessively on the mating surfaces.

When very large holding blocks or blocks with irregular parting lines are required, it may be more economical to use a steel casting that is heat-treated to a hardness of about 250 BHN. A chromium-nickel-molybdenum steel having the composition given for steel No. 14 (Table 6.3) can be specified for this purpose.

HEAT-TREATMENT OF DIE STEELS

Experience has shown that steels for die-casting dies should be harder than can be machined. Therefore, the most practical method of making a hardened die is to harden it after the impression has been machined. Only for some simple short-running zinc dies and for complicated zinc dies such as are used to cast automobile grilles is it more economical to machine the impression into a block of hardened steel. This prehardened steel usually is similar to type No. 7 (Table 6.3) and is purchased from the supplier quenched and drawn to hardnesses ranging from 200 to 300 BHN. The hardness that is specified depends upon the service required of the die and on the amount of handwork required to make it. Hard material gives longer die life but is more difficult to work by hand. Work done with power tools on steel having a hardness of 300 BHN is not too difficult (Fig. 6.18), although it is considerably slower than the machining of a softer material.

When an impression die is to be hardened after machining, an air-hardening steel that has a minimum size change on heat-treatment is

selected if possible. Nevertheless, even with this type of steel, heat-treatment may cause one or more of the following conditions to occur and thus render the die useless or require costly reprocessing.

1. The die cavity may become badly scaled and pitted, thus requiring excessive polishing that probably will result in an oversized cavity.
2. The surface of the die cavity may become carburized or decarburized, both of which are detrimental to service life.

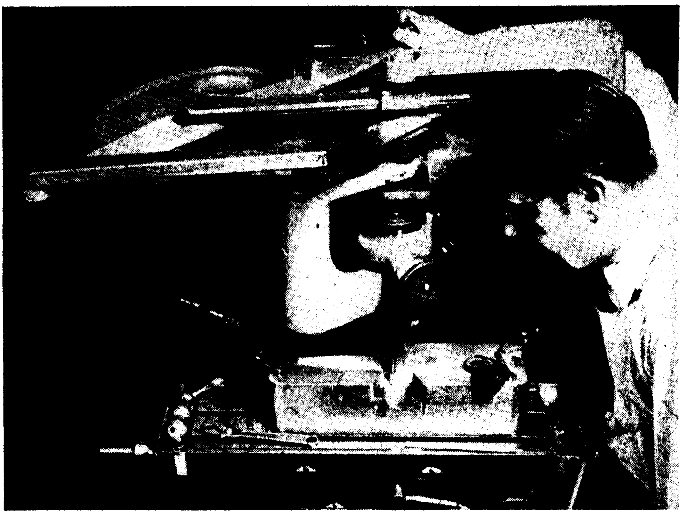


FIG. 6.18. Machining a prehardened die block. Although entirely practical, the operation is slower than on nonhardened steel.

3. The dimensions of the die or die cavity may change. While this size change is usually small, it may be critical in large dies. Also, the change in size is not always the same in all directions; if extreme care is not taken in the manufacture of the steel and in the design, layout, and heat-treatment of the die, one-half of the die may shrink and the mating half may expand, thus resulting in a serious misfit.
4. The die may distort or warp. Both of these effects are undesirable and are most pronounced on dies of irregular shape.

The causes of each of these various difficulties are fairly well understood—at least to the extent that methods have been devised to minimize their occurrence.

Oxidation, Carburization, and Decarburization. The usual methods of protecting a die against oxidation, carburization, and decarburization

when exposed to temperatures of from 1800 to 2150°F (the temperature range within which alloy die steels must be hardened) is by (1) packing carbonaceous materials around the die exterior; (2) copper-plating the surface; (3) heating the die in a controlled-atmosphere furnace; or (4) heating it in a salt bath.

Probably the oldest method of protecting a die during heat-treatment is to pack a material around it that will protect it against scaling and

FIG. 6.19. Controlled-atmosphere furnaces for heat-treating of dies. Such furnaces afford protection against carburization, decarburization, and oxidization.

carburization. These packing materials consist of clean cast-iron turnings, spent pitch coke, charcoal, or spent carburizing compound; cast-iron turnings usually permit the least amount of carburization, while spent carburizing compounds permit the most. Of course, all these packing materials must be free from foreign substances that may attack the die surface.

Controlled atmospheres are used to some extent for the heat-treatment of die-casting dies (Fig. 6.19). The atmospheres used can be roughly divided into three classes:

1. Gas produced by passing air over hot charcoal.
2. Gases produced by partial or complete combustion of hydrocarbon gases and air.
3. Gas produced by cracking anhydrous ammonia.

The first two types contain various percentages of carbon monoxide, carbon dioxide, hydrogen, methane, water vapor, and nitrogen, depending upon the type of generator used. Since carbon monoxide, carbon dioxide, methane, and water vapor react with steel either oxidizing or reducing and decarburizing or carburizing, it is necessary that a very close balance of these gases be maintained to obtain a neutral atmosphere. Unfortunately, the reactivity of these gases with steel varies with temperature. Therefore, a mixture which is neutral to the die steel at 1850°F may react with the steel at lower temperatures. Since dies must necessarily be slowly heated and held at temperature for long periods, the use of gas atmospheres 1 and 2 require very close control to obtain the desired results.

The third type of gas, prepared by cracking anhydrous ammonia, is made up of 75 per cent hydrogen and 25 per cent nitrogen. Both of these gases in the molecular state are rather inactive to steel. Since this gas forms a uniform atmosphere at all times, it is much more readily controlled and has given the best results of any of the atmospheres tried. When this gas is used, care must be taken to prevent leakage of air into the furnace. The oxygen of the air combines with the hydrogen, forming water vapor, which is strongly oxidizing and decarburizing.

A modification of a controlled atmosphere also has been used extensively. This modification consists of heating the dies in a sealed container that holds a small amount of charcoal. The gas obtained from the hot charcoal and air consists principally of nitrogen and carbon monoxide in a theoretical ratio of 66 per cent nitrogen to 34 per cent carbon monoxide. When dies are heated in this manner, slight scale is formed, which is not too serious; and a limited amount of carburization and decarburization occurs.

Another successful method of ensuring protection is to electroplate the die surfaces with copper prior to heat-treatment. The dies are first plated with a layer of copper about 0.001 in. thick and then are packed in charcoal and heated. The layer of copper prevents the die from being carburized by the charcoal, and charcoal prevents the copper from oxidizing. After hardening and tempering, the copper is stripped from the surface.

Salt-bath furnaces afford a natural protection against surface attack and are preferred for small dies that must be heated to temperatures of

2150°F or higher. Salts that do not corrode the steel must, of course, be used. One disadvantage of salt baths is that they must be kept molten at all times, even though they are used only for relatively short periods. Furthermore, the rate of heating in salt is very rapid, and there is great danger of warpage and cracking, especially when large and irregular die sections are involved; a preheat salt bath is always used before the high-temperature bath to minimize this warpage and cracking. Finally, because the salt used for high-temperature (2150°F) salt baths tends to pit die steels when they are quenched in air, it is necessary to use a quenching bath for air-hardening die steels.

The high-temperature salt bath is made up of alkali and alkaline-earth chlorides, but because barium chloride oxidizes on exposure to air and the oxides formed tend to decarburize steel, the barium oxide content of the bath should be kept below 5.0 per cent. Two methods can be used to keep the barium oxide content at a safe minimum: (1) a graphite rod can be submerged in the barium chloride bath to reduce the oxide to metal, in which case it is necessary periodically to remove the metallic particles from the graphite rod; or (2) the salt bath can be periodically changed every 10 to 30 days, depending upon the temperature that is used, or else 10 per cent or less of the bath can be remade every day. The quenching salt gradually builds up in alkaline-earth chlorides because of the carry-over from the high-temperature bath. Only alkali chlorides, therefore, are added to maintain this salt bath.

Dimensional Change. Size change during heat-treatment is usually not excessive. It generally is a characteristic of the steel, although there are reports that size change may also vary with method of heat-treatment. The amount of change varies with the direction of forging. If a pair of matching blocks are used for a die, therefore, it is desirable to have the forging direction the same in both blocks. The use of upset-forged blocks overcomes this preferential size change to a large extent, as the upset block does not have as marked directional properties as forged or rolled bars.

Warpage and Distortion. Warpage and distortion are probably the worst hazards encountered when heat-treating die-casting dies. The amount of warpage that is permissible depends upon the die being heat-treated and the place at which it occurs. In the die cavity itself, a warpage of 0.0003 in. per in. is often considered excessive. The warpage in the back of the die rarely can exceed 0.0002 in. per in. without causing difficulties.

Warpage is more a function of die shape and size than of steel composition (Fig. 6.20). Its cause is generally conceded to be uneven heating

and cooling. The light sections of a die respond more rapidly to changes in temperature than do the heavy sections. Even in a uniform block of steel, warpage occurs if one side of the block is heated or cooled more rapidly than another. The expansion or contraction that occurs as a result of such temperature differentials sets up strains that cause the die to warp.

Another cause of warpage that must be considered is the transformation of the steel from an austenitic to a martensitic structure. During

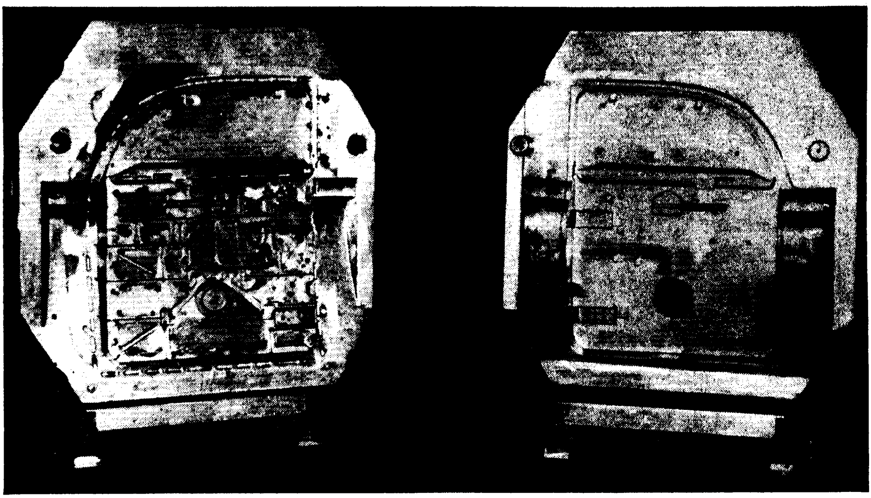


FIG. 6.20. Ejector and cover halves of what is believed to be the largest aluminum die-casting die ever built. With dies of this size, or with smaller, more complex dies, extreme care must be taken to prevent warpage and distortion during heat-treatment.

this transformation, there is a crystallographic change from face-centered cubic austenite to tetragonal or body-centered cubic martensite. This transformation is accompanied by a considerable increase in volume. If this transformation occurs in one part of a die before it occurs in another, therefore, major stresses are set up that cause warpage.

Finally, steels may have sufficient residual stress after rough machining to cause warpage. This does not often occur with annealed die steels; but if strains do exist, the steel should be strain-relieved before finish machining by heating it to 1300 to 1400°F.

To keep a die of irregular shape within the warpage limits often requires that the heat-treater use every known trick. The basic objective is to heat and cool the blocks uniformly. The furnaces must be designed to maintain uniform temperature throughout the heating cham-

ber. Programs to control the heating and holding cycle are not a "must" but are desirable, since such programs minimize the attention that must be given to the furnace and ensure more uniform heating rates.

Unless it is desired to shield a thin section that may heat too rapidly, the die blocks must be arranged in the furnace so that the faces are heated uniformly. The rate of heating is controlled by the thickness of the thickest section. As previously mentioned, it is often necessary to pack or fill large holes or recesses with asbestos, cast-iron chips, or, in some instances, a piece of steel machined to fit the cavity. When the die has a large, open U-shaped section, it is desirable to weld a heavy member across this opening to minimize temperature and strain differentials. If a steel insert is fitted into a die opening or a member welded in to compensate for temperature variations, a steel of the same composition as the die should be used.

Little or no warpage should occur on heating provided that these precautions are observed and the die is heated slowly. A recommended additional precaution, however, is to soak the steel for ½ hr per inch of thickness at a temperature just below the critical; for die steels, this temperature varies from 1500 to 1600°F.

While the rate of heating can be varied to decrease the danger of warpage, the rate of cooling is not so flexible. All steels, including air-hardening die steels, have a critical cooling rate that must be exceeded to obtain a completely martensitic structure on quenching. Therefore, the cooling rate cannot be so readily controlled.

One commonly used die steel (No. 4, Table 6.3) has a critical cooling rate from about 1600 to 1320°F; *i.e.*, according to the *time-temperature-transformation (TTT) curve,* it must be cooled through this temperature range in about 12 min to obtain a completely martensitic structure. From 1320 to 1000°F, the rate of cooling can be decreased; and from 1000°F to room temperature a slow rate of cooling will still result in complete martensitic transformation.

These cooling rates are as indicated by the TTT curve, which is developed by isothermally heat-treating small specimens, and, therefore, some discrepancy may exist when cooling a large block. As a matter of fact, there have been some indications that some low-temperature bainite is formed and, in some cases, residual austenite retained at room temperature. Despite these slight discrepancies, however, TTT curves represent the most informative data that are available.

Another factor affecting the degree of warpage in a die is the uniformity of the air quench. When a die is removed from a furnace, all faces of the die block must be cooled at a uniform rate. Care must be taken that a draft does not strike one side of the block and cause one

section to cool faster than another. The following procedure should be followed for large blocks: Cool from 1825 (hardening temperature) to 1600°F in the box in which the dies are packed; remove from box and air-cool to 1200°F (Fig. 6.21); place the blocks in a furnace which is at 600°F and furnace-cool to this temperature; hold for 2 hr at 600°F, and then either furnace-cool or air-cool to room temperature.

Cooling the die in a furnace from 1200 to 600°F and holding it at this temperature are done to prevent excessive strains and distortions during

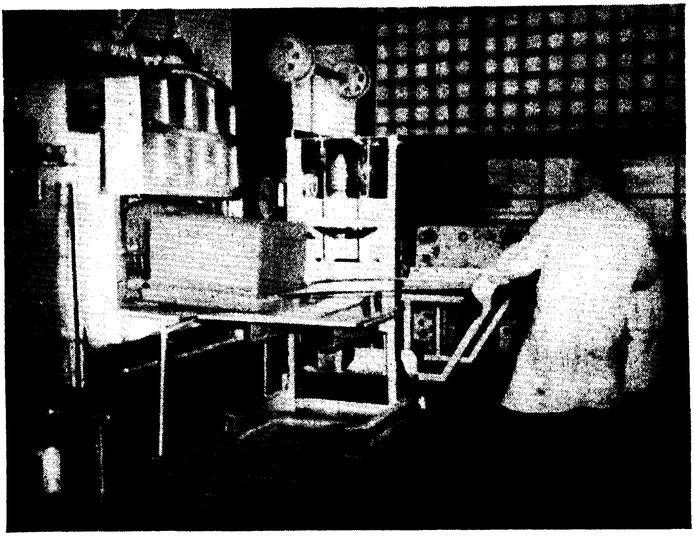


Fig. 6.21. Removing a box containing die components from the heat-treating furnace. A prescribed heating cycle then must be followed to prevent warpage.

the martensitic transformation. Because the martensitic transformation is primarily a temperature transformation that is not greatly affected by time at temperature, and because the transformation is accompanied by a considerable change in volume, it is desirable to have the transformation take place throughout the die at the same time. This is accomplished by so controlling the cooling cycle that there is little or no variation in temperature from the outside of the die to the center of the block. If the die is permitted to cool in open air from the hardening temperature to room temperature, a differential will exist between the center and outside surface. This temperature differential in large blocks has been found to be as much as 100°F at a surface temperature of 500°F.

Variations of the previously noted cooling cycle have been used with rather good success. For example, the dies may be cooled from 1825°F

to room temperature without removing them from the boxes in which they are packed. This has been done with and without air-blast cooling of the packing box. When using this method for large dies or large boxes containing many dies, there is danger of not obtaining a complete martensitic transformation. A number of steels examined after cooling in this manner have contained variable percentages of high-temperature-transformation products, indicating that the cooling rate has not been fast enough to miss the nose of the TTT curve. Also, large blocks weighing more than 1,000 lb cool too slowly in open air for the austenite to transform to martensite completely. On some critical dies in which warpage or distortion is expected to be excessive, it may be desirable to minimize this warpage by slowly cooling the die in air, even at the expense of forming some high-temperature-transformation constituents.

If a die does warp, it is possible to correct part of this warpage by various means. The die may be reheated to about 1000°F and cooled with air blasts on the section where shrinkage is desired. Another method is to reheat it and then cool it in a jig or to reheat it and place a cold jig or block on it as it is cooled. Still another method is to lay a weld on the back of the die to cause compensating warpage.

Recommended Heat-treatment for Two Common Die Steels. Steels Nos. 1 and 2 (Table 6.3) are generally used for die-casting copper-base alloys. Because of their high-tungsten content, it is necessary to quench them from about 2150°F and draw them at 1100 to 1200°F to obtain the desired hardness. Steel No. 1 is heat-treated as follows:

1. The die is cleaned to remove all foreign material that might be injurious to the surface.
2. The die is then preheated at from 400 to 1000°F, depending upon the furnace that is used. This temperature is not critical.
3. The preheated die is immersed in a salt bath (Fig. 6.22) that consists of a mixture of alkali chlorides and alkaline-earth chlorides. The bath is held at 1200°F, and the die is kept in the bath until it is up to temperature; this usually requires from 30 to 60 min, depending upon the size of the die. When the die reaches the temperature of the bath, the solidified salt that is formed around the die when it is first immersed disappears.
4. The die is then transferred to a salt bath (also a mixture of alkali chlorides and alkaline-earth chlorides), which is held at 1500°F, and is immersed in this bath for from 15 to 30 min, depending upon size.
5. The die is transferred to a barium chloride salt bath that is kept at 2150°F. It requires from 2 to 10 min to heat the die to this temperature, after which it is held at temperature for from 2 to 5 min.

6. The heated die is then quenched in the 1200°F salt bath used for the previous preheating operation. It requires from 3 to 15 min to cool the die to the temperature of the salt.

7. The die is removed from the salt bath and permitted to cool in air to about 200°F.

8. The quenched die is placed in boiling water to remove the salt that is adhered to it.

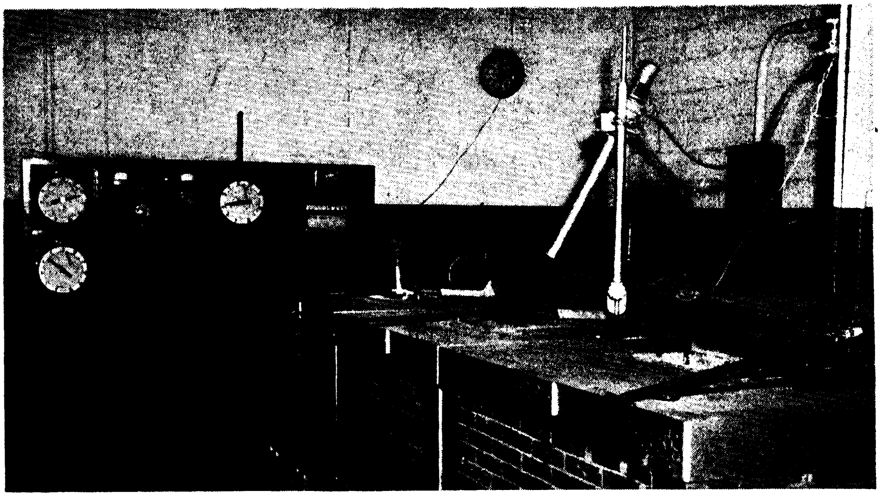


FIG. 6.22. Battery of salt-bath furnaces. These are used for heat-treatment of certain types of die and tool steels, as indicated in the text.

9. The die is drawn by packing it in cast-iron chips and heating it slowly to 1140°F. It is held at temperature for 3 hr per in. of thickness and is cooled in the box.

Steels Nos. 3 to 6 (Table 6.3) are impression die steels that are used when casting aluminum, magnesium, and zinc alloys. They are heat-treated very similarly: by air-quenching from 1800 to 1900°F and drawing to a hardness of 405 to 444 BHN at temperatures of from 1000 to 1100°F. Steel No. 4 is heat-treated as follows:

1. The steel is cleaned of any oil or foreign material that may affect the surface.

2. The dies are packed in Nichrome boxes with a small amount of charcoal. Care is taken to ensure that the charcoal does not contact the die. Holes in the die may be filled with asbestos or cast-iron turnings, or may be fitted with jigs or steel inserts, as the heat-treater sees fit. The dies are arranged in the box in such a way that there is ample space between

them so that they will heat uniformly. The cover is placed on the box, a fine sand seal being used to keep air seepage to a minimum.

3. The packed dies are placed in a cold furnace and heated slowly to from 1825 to 1850°F. The rate of heating depends upon the shape and thickness of the dies being heat-treated. An average heating rate of 150°F/hr is used for rather heavy dies. Dies of lighter section, which are heated at a faster rate, are held at 1400 to 1500°F for several hours before heating them further to 1825 to 1850°F.

4. The dies are held at temperature for 1 hr/in. of thickness.

5. The box and dies are removed from the furnace and quenched in air. The method of cooling that is used depends upon the type of die being hardened and on the heat-treating equipment that is available. Generally, the dies are removed from the packing boxes at 1825 or 1600°F and then cooled in still air. Some of the dies are arrested in the cooling cycle at 600°F by placing them in a furnace held at this temperature. In all cases, the dies are cooled to room temperature before drawing.

6. The dies are then drawn to a hardness of from 405 to 444 BHN by heating them to 1050 to 1065°F and holding them at this temperature for from 10 to 20 hr.

7. After drawing, the dies are removed from the draw furnace and cooled in still air.

8. The dies are then electrolytically pickled to loosen the thin scale that has been formed and are vapor-blasted to remove the scale.

Every die has a different cooling rate and this, of course, affects the hardness that is obtained. For the previously mentioned steel, the "as-quenched" hardness may vary from 444 to 512 BHN. Since the desired hardness is 405 to 444 BHN, the dies must be drawn or tempered as noted. A temperature of 1050 to 1065°F is usually used, and the die is kept at temperature from 10 to 20 hr.

When drawing a die that has relatively low as-quenched hardness, the hardness may either decrease or increase. The reason for an increase in hardness on drawing has been attributed to residual austenite, which is transformed to martensite on cooling from the drawing temperature. If the first drawing operation does not result in the desired hardness, a second drawing operation is required. Some heat-treating departments have specified double-drawing operations as standard practice.

When the double-drawing method is used, the first drawing operation takes from 4 to 10 hr at a temperature of from 600 to 1000°F. Its purpose is to transform residual austenite to martensite. The second draw is then performed to obtain the desired hardness.

Packing the dies in Nichrome boxes with charcoal is not entirely satisfactory; a light scale forms when the hot dies are exposed to the air for the air quench. An investigation is now under way to develop a more satisfactory method of heat-treatment.

Nitriding Die-casting Dies. A considerable variation of opinion exists regarding the advantages and disadvantages of nitrided die-casting dies,

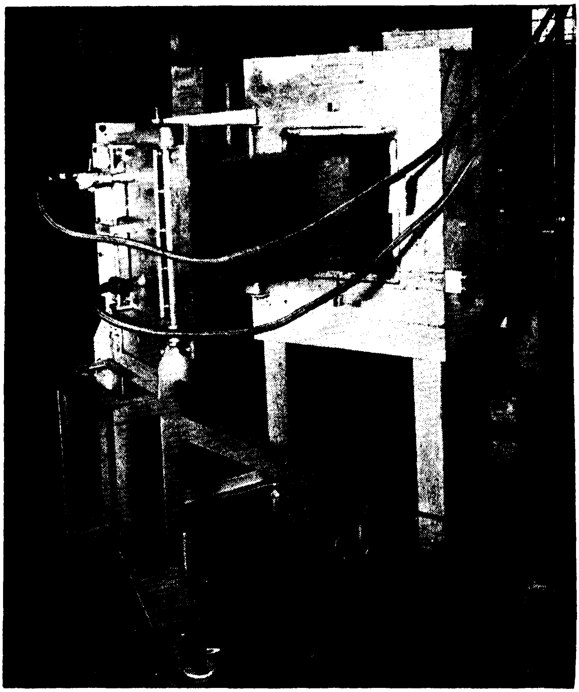


FIG. 6.23. Nitriding furnaces. Nitriding is recommended for movable die parts subject to wear and in some cases for die cavities.

although there is no question regarding the advantages gained by nitriding slideways and other wear members. From the standpoint of operation, nitriding of the die cavity is definitely advantageous since it decreases the tendency of aluminum alloys to solder and stick. Nitriding may cause the steel to heat-check prematurely, and there is a good possibility that the nitrided case will cause spalling. Another disadvantage of nitriding is that case-hardened dies are difficult to repair.

In general, most nitriding of die surfaces is done on a used die in an attempt to extend its life. It is not general practice to nitride a new die, except when the die replaces one on which production has proved

nitriding definitely to be an advantage. The nitriding procedure for dies is as follows:

1. The die is first steam-cleaned to remove all oil and dirt.
2. Oxide and other foreign materials are then removed by vapor blasting.
3. The die is polished to remove minor defects and to return it to the best possible condition.

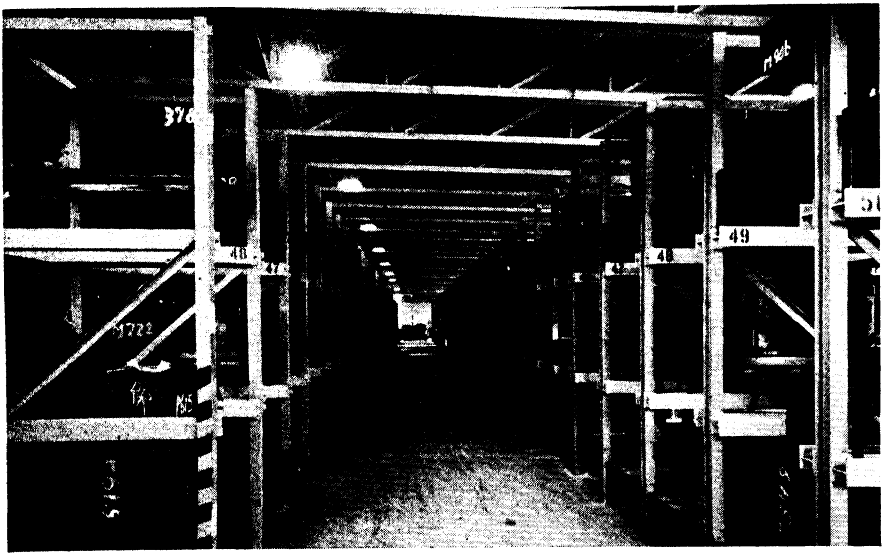


FIG. 6.24. Die storage racks in a large die-casting jobbing shop. The better the die steel, the longer is the die life and the more economical is the die-casting process.

4. It is given a final cleaning treatment with carbon tetrachloride.
5. It is gas-nitrided in a Nichrome box at 1000°F for 10 hr (Fig. 6.23). This gives a case that is thick enough to prevent soldering but thin enough so that it will not readily crack and spall.

Heat-treating Small Cores and Ejector Pins. Small movable cores and ejector pins must be heat-treated with extreme care to obtain a straight, hard pin with a soft head. Improper heat-treatment will result in premature breakage and cause costly down time for repairs. Common practice is to use a steel such as No. 10 (Table 6.3); it usually is heat-treated to a core hardness of from 32 to 42 and generally is nitrided to increase wear resistance. The head of the pin is maintained at 15 to 20 Rockwell C to eliminate breakage between the stem and the upset head.

The heat-treatment is along the following lines:

1. The pins are hung by the head in a perforated steel plate.
2. The assembly is preheated to 900°F.
3. The assembly is transferred to a vertical muffle furnace that is held at 1825°F. The pins are so located in the furnace that the heads are not heated to the furnace temperature.
4. The pins are held in the furnace for 10 min after the stems reach the furnace temperature.
5. The whole assembly is air-cooled.
6. The stems of the pins are then drawn back in a cyanide bath consisting of 50 per cent sodium cyanide and 50 per cent potassium cyanide. The bath is held at a temperature of 1000°F, and the pins are submerged for 30 min.

DIE STEELS OF THE FUTURE

The compositions of die steels that will be used in the future cannot be predicted because, if they were known, they would be in use today. However, it is possible to show what is needed in die steel and to compare present steels with those that are now in the development stage.

The most urgent need is for a good die steel for die-casting brass, because the steels now in use are good for only from 1,000 to 10,000 casting cycles. Although these steels actually are used for 5,000 to 50,000 castings, the surface finish obtained on brass die casting is not comparable with that obtained on aluminum and zinc parts. The brass die steel that is needed is one that will make 100,000 or more castings having good surface finish.

At present, brass die steels fail because of heat checking. After years of testing various alloys for heat-checking characteristics under simulated production conditions, some materials that are superior to the standard alloys in this respect have been developed. Although these materials do not heat-check, they do not have sufficient hardness, strength, and machinability to qualify as satisfactory commercial brass die materials.

The die steels for aluminum-base-alloy die casting now used are adequate, but require a high-temperature heat-treatment (having low notch-impact properties), heat-check rather early when used to cast heavy sections, and erode at the gates. Any steel that could correct any of these conditions would be very desirable and would find immediate use. Some experimental steels are being investigated, but it is too early to predict their future use in die-casting dies.

In most respects, present zinc die steels may be termed satisfactory.

Even plain carbon steel makes a good die for zinc; of course, to obtain extremely fine finishes, alloy steels must be used when the machines are operated at high shot speeds and pressures. An improved steel for zinc die casting would be a more economical one that either is lower in first cost or could be used for a greater number of castings.

One new type that appears to have promise is a precipitation-hardening steel in which the hardening constituent is the intermetallic compound of nickel and aluminum.

This particular steel has been proved to have excellent resistance to heat checking and erosion. It has good machinability in the solution-treated state and can be satisfactorily hardened at temperatures of as low as 1000°F. There has been only a single case of warpage on precipitation hardening. All these factors add up to the production of a first-quality zinc die-casting die at lower cost.

Another steel that is in the process of investigation and that appears to have possibilities for die-casting dies is an alloy hobbing steel. This steel is a low-carbon steel containing about 5 per cent chromium and 1 per cent molybdenum. It is easily hobbed, and after hobbing can be air-quenched to a satisfactory hardness. Dies made from this steel are now in operation for the die casting of both zinc and aluminum. If these dies prove satisfactory, the use of hobbed die-casting dies will be greatly increased.

CHAPTER 7

DIE-CASTING ALLOYS

Since die casting is a process for producing metallic parts, it is apparent that metallurgy must play an important part in the industry. In fact, metallurgy along with mechanical engineering has been responsible for the significant advancements in the process. It is difficult to state which of these two branches of technology has been the more important or has contributed the most. Each has had to rely upon the other; neither could have proceeded alone.

Mechanical engineering has been responsible for the physical development of the process as related to the casting mechanisms and the design and construction of dies, tools, and other equipment. Metallurgy has been responsible for the derivation of suitable casting alloys, for the development of satisfactory methods for their preparation and control, for advancements in methods of finishing die-cast parts, and for the solution to problems relating to the selection, inspection, control, heat-treatment, and performance of ferrous die materials. It also has been responsible for the development of electroplating, painting, and other finishing methods; radiography; and the study of all factors concerned with the production of sound castings.

TYPES OF DIE-CASTING ALLOYS

Since die castings are used in many types of products that function under widely diversified conditions (Fig. 7.1), it follows that a die-casting alloy which is entirely satisfactory for one application may be entirely unsuited for another. The alloy for an automobile door handle is chosen primarily for low cost, adaptability to rapid casting cycles, satisfactory surface finish, and amenability to plating. The casting for a machine gear housing may be chosen solely on the basis of strength, all other considerations being of secondary importance.

The first problem of the designer is to select the most economical alloy—on the basis of both first cost and casting cost—that will result in the highest quality part or product. In doing this, he should consider the following factors about the alloy:

1. Its mechanical properties, such as strength, ductility, and hardness.
2. The effect of aging on its properties, and the permanence of dimensions.
3. Its adaptability to the die-casting process: castability, fluidity, shrinkage on cooling, etc.
4. Its strength at both low and elevated temperatures.

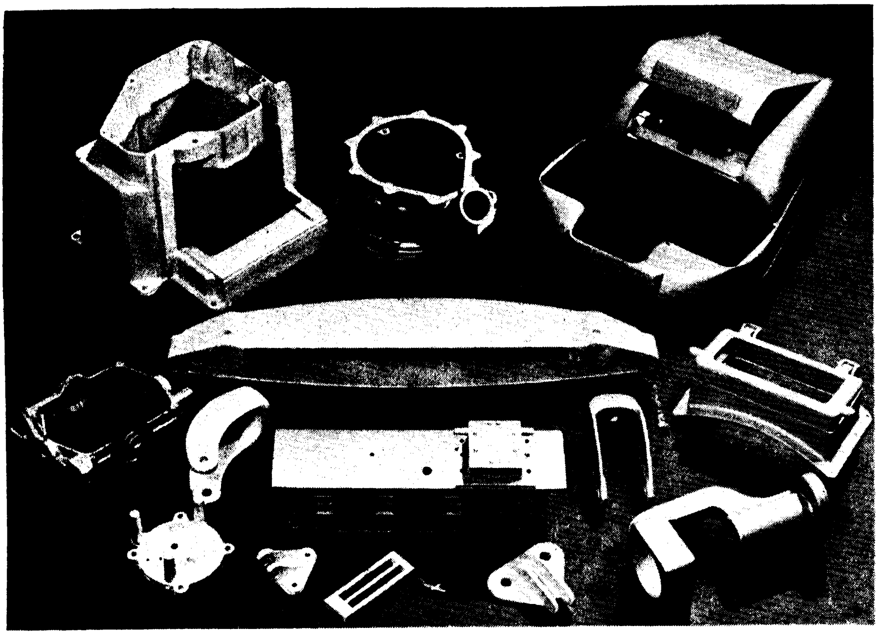


Fig. 7.1. Typical magnesium die-cast parts for application in both industrial and consumer products.

5. Its machinability.
6. Its ability to be polished, plated, painted, or finished by other processes.
7. Its corrosion resistance.
8. Its weight and cost.

To meet any or all of these specifications, the designer can select from six main groups of die-casting alloys, namely, zinc, aluminum, magnesium, copper, tin, and lead.

Zinc alloys are used for approximately 60 per cent by weight of all die-cast parts, chiefly because of economies resulting from the ease and speed with which they can be cast. In many instances, speeds of up to 500 cycles/hr can be obtained. In addition, the low casting tempera-

ture of these alloys results in low fuel cost, low die cost, and low die maintenance. They have good mechanical properties and can be readily machined and economically finished.

Aluminum has increased in die-casting usage until, at the present time, it accounts for about 30 per cent of all die casting done in this country, the reasons being that parts cast of aluminum-base alloys (1) are light in weight; (2) have excellent creep resistance, electrical and thermal conductivity, and tarnish resistance; (3) are competitive in cost with cast-iron and steel casting, formed steel parts, and many other types of castings; and (4) can be commercially and economically finished.

Magnesium die castings are used mostly for applications where lightness, the principal advantage of the metal, is a main requirement. Such equipment as portable typewriters, stenotype and other business-machine cases and housings, cameras, optical instruments, portable tools, and similar devices utilize magnesium die castings. Magnesium die castings are also used in reciprocating and moving parts in textile, conveying, and packaging machinery.

The salient properties of high strength, toughness, and corrosion and wear resistance of copper-alloy die castings—particularly brass—make them suitable for many varied uses and open to industry a source of engineering parts having the accuracy, intricacy, stability, and economy of the die-casting process. The applications of brass die castings are far too varied to give in detail, but the following partial list may suffice to indicate their potentialities: automotive gears, transmission forks, clutch parts, shock-absorber parts, pumps, bearings, electrical switchboard parts, contactor parts, brush holders, refrigerator parts, steam fittings, valves, trunion bearings, oil-burner parts, general engineering fittings, and household hardware.

Tin die castings were extensively used in the past for antifriction bearings, especially for automotive use. This use, however, has greatly dwindled, and today tin-alloy die castings are not being used for bearings because of the substitution of other materials and better methods for producing bearings. Tin die castings are used particularly for their corrosion resistance in such parts as soda-fountain equipment, milking machines, syrup pumps, dental appliances,. and surgical instruments.

Finally, lead alloys (Table 7.1) are usually applied where a low-cost, noncorrodible metal is required and when strength, hardness, and other mechanical properties are unimportant. Parts that must withstand the action of strong mineral acids, such as fire-extinguisher parts, batteries, and chemical apparatus, are produced as lead die castings. They are used in X-ray equipment because of their resistance to the passage of

X rays. The high specific gravity of lead is taken advantage of in the use of lead die castings for governor weights and similar devices.

TABLE 7.1. CHEMICAL COMPOSITIONS * OF COMMON LEAD- AND TIN-BASE ALLOYS

Alloy No.	Tin, per cent		Antimony, per cent		Lead, per cent		Copper, per cent		Max percentage of other elements			
	Min	Max	Min	Max	Min	Max	Min	Max	Iron	Arsenic	Zinc	Aluminum
1	90	92	4	5	..	0.35	4	5	0.08	0.08	0.01	0.01
2	80	84	12	14	..	0.35	4	6	0.08	0.08	0.01	0.01
3	64	66	14	16	17	19	1.5	2.5	0.08	0.15	0.01	0.01
4	4	6	14	16	79	81	...	0.50	....	0.15	0.01	0.01
5	..	..	9.25	10.75	89	91	...	0.50	....	0.15	0.01	0.01

* As given in ASTM B102-48.
The desired amount of each element is the arithmetic mean of the minimum and maximum values.

The mechanical properties of both lead and tin alloys are very low (Table 7.2), and die castings of them therefore represent only a very small percentage of the total die-casting consumption. For some specific applications, however, such as those just discussed, die castings of these alloys are quite indispensable. In such cases, one of the standard alloys whose composition was given in Table 7.1 generally is specified.

TABLE 7.2. AVERAGE PHYSICAL PROPERTIES OF TIN- AND LEAD-BASE ALLOYS *

Alloy	Tensile strength, psi	Elongation in 2 in., per cent
1	10,300	22.4
2	13,500	14.3
3	11,800	3.75
4	10,900	6.1
5	7,900	11.2

* ASTM Committee B6, Subcommittee III Standards, 1946, p. 211. Average results of three laboratories of six round, die-cast test specimens.

The principal types of alloys in each of these six classifications are given in Table 7.3 along with their salient advantages and limitations. Each will be discussed in detail under subsequent sections of this chapter. It is impractical, of course, to list all the possible variations that are available or that are melted by individual shops, but none varies

greatly, either in composition or in properties, from the ones classified in the table.

Zinc-alloy die castings were first produced about 1907, following the commercial development of the die casting of tin and lead alloys, which utilized the principles of the Mergenthaler linotype machine, *i.e.*, the use of a cylinder and plunger submerged in molten alloy.

Because of the strict limitations of tin and lead alloys as to strength and low fusion points, the early experimenters in die casting set out to develop the process for casting higher melting point alloys. The alloys of zinc, being next higher in melting point, were then tried.

The first zinc die-casting alloys were made up with any kind of elementary zinc available and alloyed with small additions of copper and tin, the latter ranging in content from 4 to 8 per cent. Some aluminum, about 0.5 per cent, was a necessary addition to prevent the formation of zinc-iron sludge at the bottom of the casting pot. These alloys were weak, hot-short, and subject to rapid disintegration and deterioration (Fig. 7.2).

However, because of the great economy associated with lower melting point alloys, great effort was expended to develop better and more suitable zinc alloys. During the years 1915 to 1920, many alloy compositions were offered and exploited with exaggerated claims for their virtues. Ternary alloys of copper-aluminum and zinc supplanted the copper-tin alloys without much improvement in service life. Alloys containing about 3 per cent copper, 12 per cent aluminum, and the remainder zinc showed fair mechanical properties as cast, and test bars of this alloy could be bent 90 to 120 deg without fracture. These alloys suffered a great loss in ductility on aging, however, and in time became brittle. In addition, even with the use of zinc of the highest purity then available—99.94 per cent—the alloys were susceptible to intergranular corrosion and dimensional changes, especially under hot, humid conditions.

Alloys containing a lower aluminum content, about 5 per cent with the high-grade zinc, were next used and gave better all-around results, but they still were unsatisfactory in corrosion and aging characteristics. In the years between 1920 and 1930, a concentrated study of the mechanism and cause of failure of zinc-base alloys was undertaken. The excellent work of Williams,[1]* Brauer and Peirce,[2,13] Hanson and Gaylor,[22] Fraenkel and Spanner,[21] Johnson,[3] Anderson,[5,6] Werley,[5,6,17] Wilcox and Fuller,[9,10,11] and others contributed greatly to determining the causes of failure upon aging.

Williams was one of the first to study the causes of the swelling of

* Superior numbers refer to Bibliography at the end of the chapter.

TABLE 7.3. APPLICATIONS AND LIMITATIONS OF 20 STANDARD DIE-CASTING ALLOYS

Alloy: Base and ASTM	Alloy: Type	Advantages	Limitations	Typical applications	Remarks
Tin B102-48	No. 1 No. 2 No. 3	Genuine babbitt alloy. Harder composition. High-lead content for lower cost.	High cost, low strength and hardness. Low resistance to fatigue, low-creep strength.	All these alloys are used for babbitt antifriction bearings, soda-fountain equipment, milking machines, dental appliances, surgical instruments.	Die castings of tin-base alloys were formerly widely used for bearings but their use has been greatly curtailed, primarily because of cost, also other methods for making bearings have displaced die casting. Tin-base die castings are now being used chiefly for corrosion resistance and where their relatively poor mechanical properties can be tolerated.
Lead B102-48	No. 4 No. 5	Resistance to attack by mineral acids, easy to cast, unlimited die life.	Low tensile and creep strength, low hardness.	All these alloys are used for storage-battery parts, fire-extinguisher parts, low-cost bearings, governor weights.	Similar to tin-base die castings. The use of lead-base die castings is limited strictly to applications indicated by their specific properties. Both tin- and lead-base die castings make up only a very small percentage of the total consumption of die castings.
Zinc B86-46	No. XXI No. XXIII No. XXV	Higher initial strength and hardness. Slightly better aging properties than other zinc alloys. Slightly better surface corrosion resistance when used without surface protection.	Zinc-base die-casting alloys have relatively poor creep strength and are subject to cold flow when excessively loaded. They cannot be employed where applications are required to be heated constantly above 200°F. Zinc alloys suffer loss in impact strength at subnormal temperatures, a factor which must be taken into consideration in design. Alloy XXI has poorer aging properties than the other alloys which are displacing it.	The automotive, electrical, business-machine, machine tools, household utilities, and other industries consume extremely large tonnages of zinc die castings.	Variation in alloy is primarily in copper content. All zinc alloys can be cast at high speed, have good mechanical properties, and can be economically machined and finished. Zinc die castings account for about 60 per cent of total die-casting consumption. The total consumption of zinc die castings in 1948 amounted to 100,000 tons in the automotive industry alone.
Aluminum B85-49T	S4	Softer and more ductile than other aluminum alloys. Good corrosion resistance.	Relatively difficult to die-cast. Lower mechanical properties and poorer machinability than other aluminum alloys.	Used primarily for parts which must be riveted or otherwise cold-worked to take advantage of the high ductility.	Aluminum-base alloys account for about 30 per cent of total die-casting tonnage. These alloys can be mechanically finished to high polish and used without further treatment. They are most versatile for finishing, plating, painting, anodizing.

	S9	Possesses excellent castability, high hot strength, good corrosion resistance, low thermal expansion, good thermal and electrical conductivity.	Relatively poor machinability. Polished luster duller than silicon-free aluminum alloys.	Large, intricate-shaped parts having very thin wall sections and where maximum corrosion resistance is required.	They have excellent dimensional stability and can be machined to close tolerances. Light weight is important in many applications as is the corrosion resistance of these alloys. Good electrical conductivity accounts for wide usage in electrical industry. In general aluminum alloys are less susceptible to changes in temperature than are other base alloys. Die-cast aluminum parts are generally competitive with iron and steel castings, formed-steel parts, and forgings.
	SC5	Fair castibility but generally inferior to S9 and SC6 alloys.	Limited to relatively small and heavy sectioned castings. Practically displaced by SC6 alloy.	Almost wholly being displaced by SC6 alloy.	
	SC6	Good general-purpose, secondary die-casting alloy. Excellent castability. Good mechanical properties. Can substitute for S9 alloy.	Poorer corrosion resistance than the copper-free alloys. Must be protected when exposed to severe atmospheric conditions.	Excellent general-purpose die-casting alloy.	
	SG2	Similar in all details to the S9 alloy but possessing better mechanical properties.	Same as for S9 alloy.	Same as S9 alloy.	
	ALCOA 218	Has good mechanical properties, especially impact strength. Takes a high-white polished luster. Excellent corrosion resistance. Good machinability. Can be anodized and colored better than other alloys.	More difficult to die-cast than other alloys.	Cooking utensils and similar applications requiring maximum corrosion resistance and high polished luster.	
Magnesium B94-49T	AS100	....	Poor tarnish resistance: magnesium parts are required to be treated for surface protection. Somewhat more difficult to handle in molten state than other alloys. Loss of metal through oxidation and burning is larger than for other alloys. Magnesium die castings are generally higher in cost than are aluminum.	All these alloys are used for portable typewriters, stenotype and other business-machine housings, electric-motor housings, end bells, etc., aircraft parts, toy and novelty parts.	Magnesium die castings are used chiefly where lightness or portability is the main requirement; also in reciprocating and moving parts for textile, conveying, and packaging machinery, where the saving in weight and fatigue are important. Ultra-lightness (lightest of all metals). Good vibration damping, rigidity, and excellent machinability are the outstanding advantages of magnesium alloys.
	AZ91B	General-purpose die-casting alloy. AS100 alloy is being displaced by AZ91 alloy.			
	AZ91A	AZ91A possesses best corrosion resistance in unprotected state. Otherwise its advantages are the same as those of AZ91B.			
Copper B176-49T	A	General-purpose low-cost brass alloy, good machinability. Most suitable alloy for soldering.	Poorest mechanical properties of all brass alloys. Absence of silicon promotes greater loss of zinc in molten state.	Household and hardware parts, automotive structural parts, plumbing hardware, electrical contactors, brush-holders.	Brass die castings possess the best mechanical properties and corrosion resistance of all other types and have excellent castability. However, their costs are higher, primarily because of the limited life of the dies.
	B	General-purpose high-strength brass die-casting alloy.	Slightly more difficult to machine than alloy A.	Switchboard parts, refrigerator parts, ordnance parts, marine fittings.	
	C	Highest strength and hardness of all alloys. Excellent for wear resistance.	Most difficult to machine. Machinability commensurate with high hardness.	C alloy particularly suited for parts requiring wear resistance as well as high strength and fatigue resistance.	

zinc die castings. His pioneer investigations indicated that this type of failure was brought about by heat and moisture such as is found in the tropics. He was the first to use an accelerated laboratory test to cause failure of zinc die castings, and this test eventually evolved into the present steam or water-vapor test which has been so useful in the development of zinc die-casting alloys.

Brauer and Peirce followed up the work done by Williams with the accelerated water-vapor test and ultimately showed that swelling and

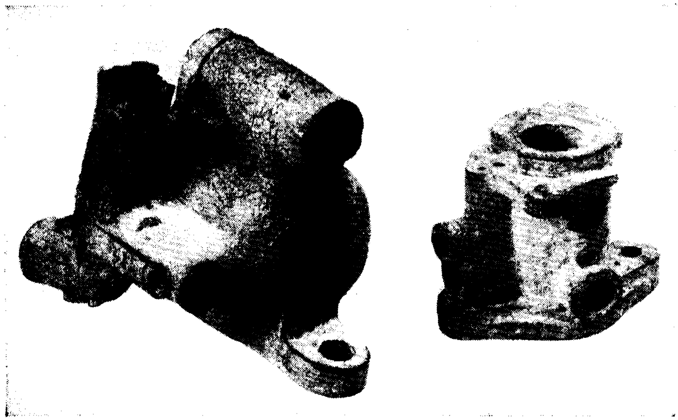


Fig. 7.2. Early zinc die casting that failed by intergranular corrosion. Such deterioration has been overcome by use of high-purity zinc.

cracking were brought about by intergranular corrosion connected with the aluminum content but stimulated by small amounts of impurities. Such impurities as lead, tin, and cadmium were the most powerful accelerators in zinc-aluminum-copper alloys. On the other hand, copper exerted a protective effect. The result of these investigations showed definitely that the permanence of these alloys was dependent upon the purity of the zinc used and indicated the need for even purer metal than was then available in commercial quantities.

Even these substantial improvements were not enough. The protective action of the copper content and the reduction in impurity content to very low levels did not eliminate intergranular corrosion. Peirce and Anderson* then discovered that magnesium in small amounts (about 0.05 per cent) in combination with the use of 99.99 per cent pure zinc would eliminate intergranular attack. Pack and Fox † found lithium to act similarly. Magnesium is used today because of its greater avail-

* Patent No. 1,596,761.

† Patent No. 1,767,011.

ability. The addition of magnesium permitted decreasing or eliminating the copper content and resulted in alloys free from undesirable aging characteristics.

According to the accepted diagram for the zinc-aluminum alloys, shown later under Aluminum Alloys, the present type of zinc alloy containing about 4 per cent aluminum consists of a eutectic between zinc-rich phases. The minor aging in these alloys was found by Fuller and Wilcox to be connected with the precipitation of excess aluminum from solid solution in the zinc-rich material. The distribution of magnesium in this structure is not known precisely, but it is believed to concentrate somewhat in the grain boundaries and to eliminate intergranular corrosion by changing the grain and grain-boundary potential differences.

The work of these pioneers and others contributed much toward the development of the present zinc die-casting alloys. Keeping the detrimental elements to the minimum or tolerance-limit amounts can only be ensured by the use of the highest purity zinc, the 99.99 per cent grade which first appeared on the market at the end of 1928. Since that time, special high-grade zinc of this purity has been the standard for zinc die castings. It is recognized that no zinc of lower quality can be tolerated in zinc die-casting production. When this became known, this grade became the basis for the ASTM B86-46 specification for zinc die castings.

METALLURGY OF ZINC-BASE DIE CASTINGS

Typical analyses of several grades of special high-grade zinc are given in Table 7.4. It will be noted that one of these products shows an average lead content of 0.0045 per cent. This content is considered the maximum amount that can be tolerated, since even with this small quantity, special care must be taken to use only other metals of high quality in preparing the zinc alloy, notably aluminum. For instance, if the lead content of the pure zinc is 0.004 per cent, the lead content of the aluminum must be kept under 0.02 per cent so that the lead content in the ultimate casting can be kept under or appreciably below the 0.007 per cent maximum.

Table 7.5 shows the chemical composition of the three standard zinc-base die-casting alloys covered under ASTM B86. It will be noted that these three alloys, which have been adopted by all standards groups, are based on the use of a 99.99 per cent grade of zinc. They all contain approximately 4 per cent aluminum and vary only in copper content. Alloy XXI, having 2.75 per cent copper, is gradually being abandoned in favor of the other two alloys, because it shows poorer aging characteristics. There is little to choose from between alloy XXIII and alloy

TABLE 7.4. TYPICAL ANALYSES OF 99.99+ PER CENT PURE ZINC

Supplier	Chemical composition, per cent			
	Lead	Cadmium	Iron	Zinc, by difference
A	0.0008	0.0001	0.0007	99.9984
	0.0010	0.0005	0.0010	99.9975
B	0.0035	0.0010	0.0007	99.9948
	0.0045	0.0020	0.0010	99.9925
C	0.0015	0.0010	0.0008	99.9967
	0.0025	0.0015	0.0009	99.9951
D	0.0025	0.0010	0.0008	99.9957
	0.0035	0.0030	0.0010	99.9925

TABLE 7.5. CHEMICAL COMPOSITION OF STANDARD ZINC-BASE ALLOYS *

Metal	Composition, per cent		
	Alloy XXI	Alloy XXIII	Alloy XXV
Copper	2.5 to 3.5	0.10 max	0.75 to 1.25
Aluminum	3.5 to 4.5	3.5 to 4.3	3.5 to 4.3
Magnesium	0.02 to 0.10	0.03 to 0.08	0.03 to 0.08
Iron	0.100 max	0.100 max	0.100 max
Lead	0.007 max	0.007 max	0.007 max
Cadmium	0.005 max	0.005 max	0.005 max
Tin	0.005 max	0.005 max	0.005 max
Zinc	Remainder	Remainder	Remainder

* As given in ASTM B86-46.

XXV as shown in Table 7.6. Alloy XXIII possesses somewhat better aging properties over a long period of time, although it initially has a lower tensile strength and hardness. Tables 7.7 and 7.8 give a comparison of the mechanical properties of these alloys at different temperatures. Alloy XXV possesses slightly better surface corrosion resistance when used without surface protection.

TABLE 7.6. EFFECT OF AGING ON ZINC-BASE ALLOY DIE CASTINGS *

Property	Aging period	Alloy XXIII	Alloy XXV
Impact strength,† ft-lb...	As cast	43	48
	After 10 years indoor aging	41	40
Tensile strength, psi......	As cast	41,000	47,600
	After 10 years indoor aging	35,000	39,300
Elongation in 2 in., per cent.............	As cast	10	7
	After 10 years indoor aging	16	13
Expansion (growth), in. per in...............	After 10 years indoor aging	0.0005	0.0004

* Data submitted by courtesy of the New Jersey Zinc Company.
† Unnotched bar, ¼ by ¼ in.

TABLE 7.7. OTHER PROPERTIES AND CONSTANTS OF ZINC-BASE ALLOY DIE CASTINGS *

Property	Alloy XXIII	Alloy XXV
Brinell hardness......................	82	91
Compressive strength, psi...............	60,000	87,000
Electrical conductivity, mhos/cm cube at 20°C..............................	157,000	153,000
Melting point, °C......................	380.9	380.6
Melting point, °F......................	717.6	717.1
Modulus of rupture, psi................	95,000	105,000
Shearing strength, psi.................	31,000	38,000
Solidification point, °C................	380.6	380.4
Solidification point, °F................	717.1	716.7
Specific gravity.......................	6.6	6.7
Specific heat, cal/g/°C.................	0.10	0.10
Thermal conductivity, cal/sec/sq cm/cm/°C at 18 C.........	0.27	0.26
Thermal expansion per °C..............	0.0000274	0.0000274
Thermal expansion per °F..............	0.0000152	0.0000152
Transverse deflection, in................	0.27	0.16
Weight, lb/cu in......................	0.24	0.24

* Data courtesy of the New Jersey Zinc Company.

TABLE 7.8. MECHANICAL PROPERTIES OF ZINC-BASE ALLOYS AT

Property	Temperatures					
	−40°C −40°F	−20°C −4°F	0°C 32°F	21°C 70°F	40°C 104°F	95°C 203°F
Alloy XXIII:						
Tensile strength, psi......	44,800	43,700	41,300	41,000	35,550	28,300
Impact strength (¼ by ¼-in. bars), ft-lb	2	4	23	43	42	40
Brinell hardness..........	91	87	82	82	68	43
Elongation in 2 in., per cent	3	4	6	10	16	30
Alloy XXV:						
Tensile strength, psi......	48,900	49,400	48,300	47,600	42,900	35,100
Impact strength (¼ by ¼-in. bars), ft-lb	2	4	41	48	46	43
Brinell hardness..........	107	194	99	91	89	62
Elongation in 2 in., per cent	2	3	6	7	13	23

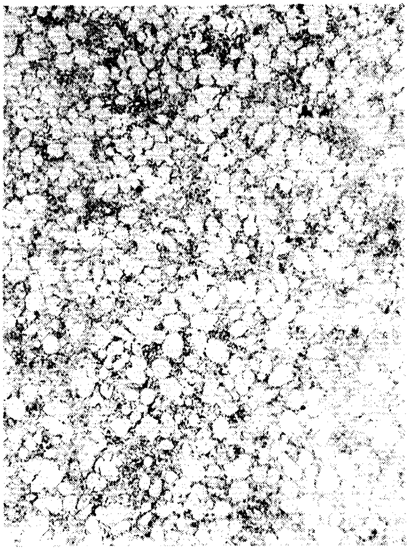
* Data courtesy of New Jersey Zinc Company.

The amounts of the various elements in these alloys have been carefully established after many years of experience and thorough testing. While a minimum and a maximum content have been established for each constituent, there is an optimum content for each that produces the best all-around results. In general, the effect of alloying elements on zinc die castings can be summarized as follows:

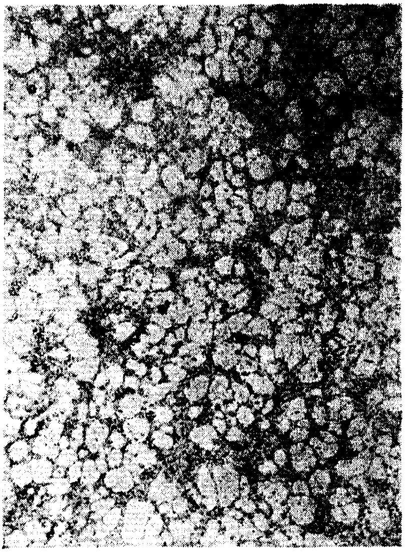
Aluminum. While the limits of the aluminum content are specified as from 3.5 to 4.3 per cent, aluminum appreciably above 4.3 per cent adversely affects impact strength. With 5 per cent aluminum the alloy becomes brittle. Aluminum below the minimum of 3.50 per cent results in poorer castability and lower mechanical properties.

Copper. Copper increases tensile strength and hardness. However, copper slightly reduces impact strength and dimensional stability on aging. Alloy XXIII can tolerate a copper content of up to 0.40 per cent without loss of properties on aging. Alloy XXV is not seriously affected by copper contents slightly outside the specification limits. Copper contents appreciably above the maximum will increase hardness and strength, but will also cause loss of impact strength and more dimensional growth on aging than if the copper were held at the optimum amount.

Magnesium. Magnesium is a necessary addition to zinc alloys, primarily because it acts as an inhibitor of subsurface corrosion. The optimum content is 0.040 per cent; a minimum of 0.03 per cent is necessary to maintain freedom from intergranular corrosion. Magnesium above 0.05 per cent, and especially approaching the 0.08 per cent allowed in the specifications, is conducive to hot-shortness in casting and to



Alloy XXIII



Alloy XXV

FIG. 7.3. Photomicrographs of two standard ASTM zinc-base-alloy pressure die casts. Both were taken at 500× and etched in 1 per cent hydrochloric acid in alcohol.

decreased impact strength in the part. Magnesium to a great degree counteracts the effects of small amounts of lead and tin.

Lead. Lead should be kept under 0.007 per cent to prevent occurrence of subsurface corrosion. No difficulty will be experienced in holding to this maximum lead content. However, care must be exercised in the selection and use of the aluminum alloying ingredient. The aluminum should not contain more than 0.02 per cent lead. Contamination of the melt by lead-containing materials such as solder, foil, cigarette wrappers, and paint must, of course, be guarded against.

Cadmium. Unless contamination by material containing cadmium occurs, there is no difficulty in holding to the 0.005 per cent maximum set forth in the specifications on zinc alloys, a content which does not seem to have so serious an effect as the same amounts of tin and lead.

Tin. Tin, like lead, promotes subsurface corrosion and therefore should be kept at a minimum. The results of extensive experimental work on the effect of tin establishes the maximum safe limit as 0.005 per cent if magnesium is present. If it were not for the magnesium content present in the alloy, the tin limit would have to be under 0.001 per cent.

Iron. About 0.02 per cent iron is soluble in the liquid zinc alloy. Iron in excess of this amount combines with aluminum and rises to the surface of the melt, where it is periodically removed as dross. Iron up

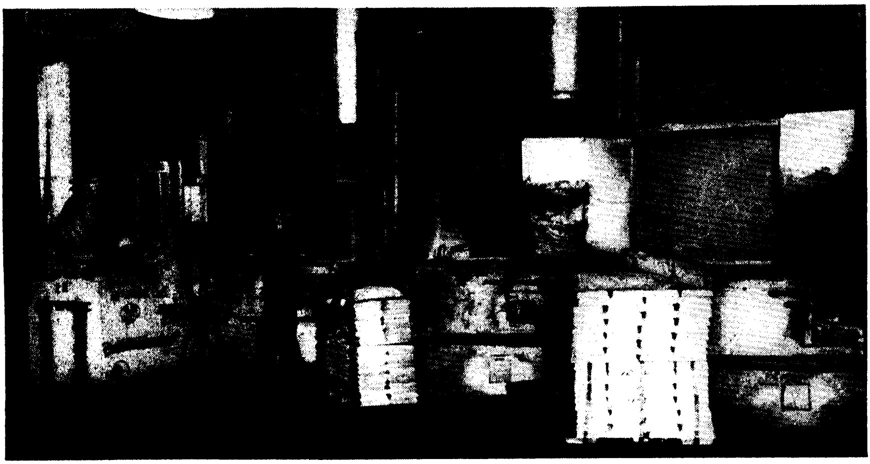


FIG. 7.4. Large pot-type furnaces for melting and alloying of zinc. Capacity may range from 2,000 to 8,000 lb, and the units may be gas- or oil-fired.

to 0.10 per cent maximum will have no effect on permanence of properties and dimensions. If, through carelessness, any of the high-iron aluminum compounds should inadvertently get into the casting, they will show up as hard spots and affect machinability.

Although there is some difference in the grain structure of zinc alloys containing various amounts of these alloys, the structure of the three standard alloys is quite similar. A photomicrograph of two of these standard alloys is shown in Fig. 7.3.

Melting and Casting Procedures for Zinc Alloys. Melting operations for zinc alloys are commonly carried out in pot-type furnaces (Fig. 7.4), using a cast-iron pot of 2,000 to 8,000 lb capacity. These pots are held in a suitable furnace fired by gas or oil and are fitted with sheet-metal hoods that connect with a stack to carry off fumes—particularly from fluxing treatments.

Starting usually with a substantial molten "heel," the required amount of aluminum for the heat is charged. The aluminum may be in the form

of small ingots of 99 per cent purity or better, or may be added in the form of shot, which is more convenient. Shot of suitable purity, with special emphasis placed on the specification for the maximum tin, lead, and cadmium contents, is readily obtainable in bags of uniform weight, which greatly simplifies the making up of the heats. The shot may also be specified to contain about 1 per cent magnesium, which will automatically take care of the magnesium content of the finished alloy; otherwise, small additions of elemental magnesium are necessary. Another

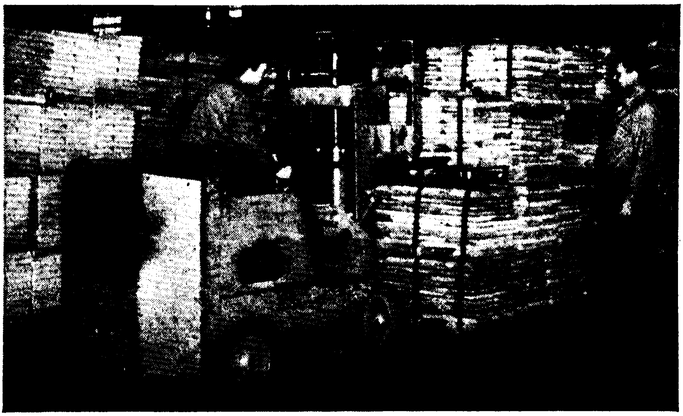


FIG. 7.5. Metal-storage department in a large die-casting plant. Slabs may be obtained strapped together to facilitate handling.

advantage is that shot is more readily dissolved in the molten zinc than is an ingot.

In preparing copper-containing alloys such as alloy XXV, it is customary to introduce the copper, aluminum, and magnesium by means of an alloy of about 20 per cent copper, 0.8 per cent magnesium, and the remainder aluminum, thereby making all alloying additions at once and eliminating the tedious stirring which would be necessary if each of the alloying elements were added separately.

The additional amount of slab zinc of 99.99 per cent purity is charged on top of the heel and melted down. The zinc, in the form of slabs weighing about 50 lb each, may be obtained from the supplier strapped together so that a large number of slabs can be handled as a unit (Fig. 7.5). The units are readily handled with a mechanical lift truck, and each unit can be weighed in from the car and stored away in a manner convenient for recording and for taking inventory. When weighing out zinc for making heat charges, the units can be adjusted to a proper weight by the addition or deduction of a slab or two as required.

Solution of the alloying constituents into the molten zinc is best accomplished with a mechanical stirrer consisting of a motor-driven shaft on which are mounted two three-bladed propellers, one pitched up and the other one down, revolving at a speed of 400 rpm. By proper adjustment of the angle at which the shaft is inserted in the molten bath, a vortex can be made to form in the revolving bath of alloy as shown in Fig. 7.6. This vortex draws the aluminum shot to it, sucks it underneath, and throws it back up to the surface at the sides of the pot. An effective stirring action is thus obtained, and the shot is dissolved completely in a few minutes. The dross that floats to the surface of the melt after the aluminum has dissolved is than skimmed off, and the alloy is ready for delivery to the casting machines.

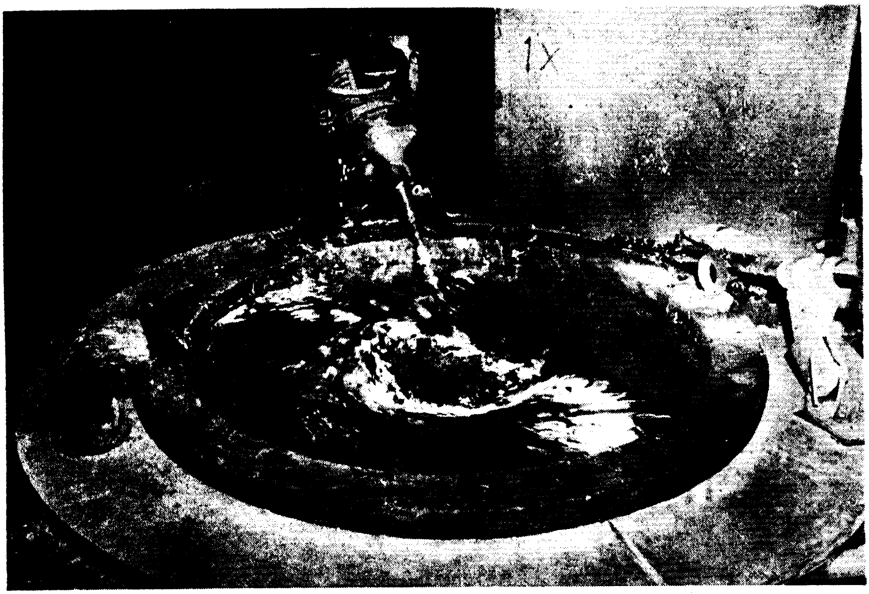


Fig. 7.6. Stirring alloying elements into molten zinc bath. Alloys usually are added in the form of shot.

The remelting of gates, overflow, fins, and scrap castings from the inspection department is done in similar furnaces. A convenient scrap-handling system is obtained by fitting these furnaces with chutes that lead from a conveyor. The conveyor can be run past each of the scrap-melting furnaces and can be made to empty into any one furnace or all simultaneously, at will.

As scrap is added and melting continues, a layer of oxide and entrained metal is formed on the surface of the molten bath and must be removed

periodically. Most of the entrained metal is freed and the oxide removed by a drossing operation that consists of applying a suitable flux such as zinc and/or ammonium chlorides. A small amount of flux is spread uniformly over the surface and then vigorously worked into the melt. The flux reacts with evolution of copious fumes, releasing entrained metal and causing the remaining oxide and flux to form into a dry powdery dross, which then is skimmed off. Removal of the accumulated dross is done with a concave spadelike tool perforated with ½-in. holes.

Recovery of metal from turnings, flashes, and other scrap that is swept from the floors of the inspection and machining departments, and from the skimmings that are recovered from the new alloy heats and casting machines, is carried out in a manner similar to that of any other remelting, except that, since a great deal of dirt and oil is carried in with the sweepings, smaller quantities are melted between drossings, and more flux is required. Starting with an alloying pot half full of molten alloy, about 1,000 lb of sweepings, depending upon the character of the material, is charged and worked down into the bath. Flux is applied and drossing carried out as described previously. When the surface of the bath is clear, another charge of sweepings is made and the operation is repeated until the pot is full.

It is necessary to point out that all chloride fluxes remove magnesium from the alloy. Three pounds of flux per ton of alloy usually produces an insignificant loss, but greater amounts can remove all the magnesium. Then, after the composition of the melt has been checked and the necessary additions made, the heat can be mixed with the regular run of alloy and delivered to the casting machines.

The fact that the attack of these zinc alloys on iron is comparatively slow makes it possible to pump them in the casting machines, using a specially designed alloy-steel centrifugal pump; pumping eliminates the labor of ladling and greatly facilitates handling of the molten alloy. A convenient arrangement is to place the casting machines and alloying pots along both sides of a track on which a power-driven truck fitted with pots and pumps can run back and forth, with the discharge pipes overhanging the casting-machine pots. The pots on the truck are easily filled by pumps in the alloying pots as shown in Fig. 7.7 and the metal is in turn pumped into the casting-machine pots. With this arrangement, one man can keep 40 or 50 rapidly running casting machines supplied with metal. The casting temperature of the zinc alloy does not exert too great an influence or finish on properties unless it exceeds 800°F, which should be considered the maximum casting temperature. Generally zinc die castings are produced at a temperature of about 775°F.

The importance of controlling the temperature of die-casting dies

during casting is well established, since this factor affects structure, appearance, and properties (see Die Temperature, page 143).

Extreme precautions must be taken to prevent contamination of the alloy throughout its use by detrimental elements, particularly lead, tin, and cadmium. Considering the low maximum amounts of these elements allowed in the zinc die castings, the need for such care can readily be

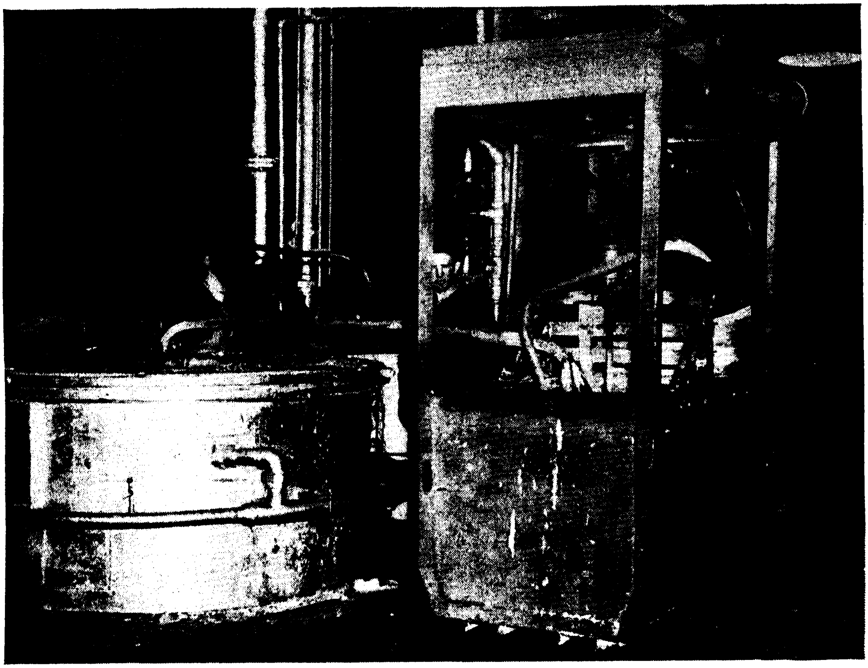


FIG. 7.7. Pumping molten zinc alloy from a melting furnace to a power-driven truck. It then is transferred to the holding furnaces on the casting machines.

seen. The plant for the die casting of zinc alloys should be kept entirely divorced from the casting or fabrication of other alloys if such alloys may contain any of the detrimental elements. Further, care must be exercised with respect to accidental contamination by extraneous substances that may contain any of the harmful elements. Lead hammers, counterweights, vise jaw linings, grinding wheels with lead centers, or even the practice of lagging machines to concrete floors with lead should never be permitted to be used in a zinc die-casting plant. Other sources of contamination that have been encountered in the past are leaded bronze or brass inserts, cadmium-plated inserts, tobacco and other lead-tin-foil wrappings, solder, matrix or similar low-fusion-point alloys, and all like articles containing detrimental elements.

Also, the complicated electrical connections of a modern casting machine interject the possibility of contamination from soldered connections, fuse links, and similar materials. In view of these and myriad other sources of contamination, it is obvious that no matter how much care is exercised there is always a possibility of the debasement of the zinc

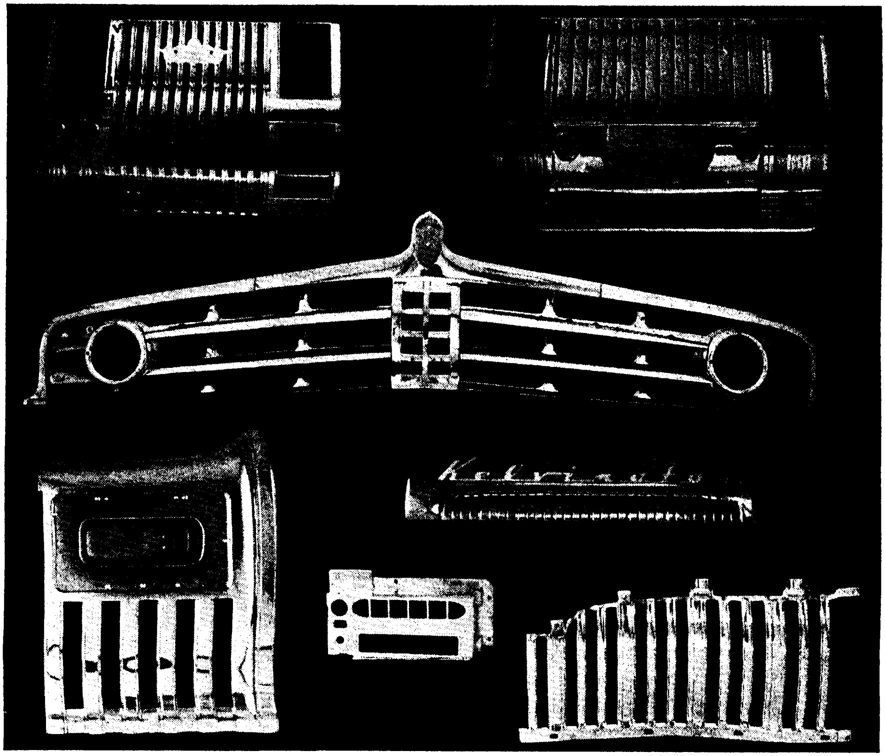


FIG. 7.8. Chromium-plated zinc-base die castings for the automotive, radio, and home-appliance industries.

alloy. Constant vigilance and continual checking by the metallurgical department to maintain the zinc-alloy specification limits is an absolute necessity.

Applications for Zinc Die Castings. The automotive industry is the largest single user of zinc die castings. Automotive radiator and radio grilles (Fig. 7.8), louvers, trim moldings, hardware, carburetors, and fuel pumps are but a few of the numerous applications. In 1949, it was estimated that about 90,000 tons of special high-grade zinc was used in the production of zinc die castings for passenger cars, and another 10,000

tons was used for truck parts. The weighted average is estimated at 35 lb per car.

The electrical-appliance industry utilizes zinc die castings for washing machines, ironers, lighting fixtures, radio chassis, tuning devices, microphones, grilles, motor housings, telephone bases and other parts, thermostat housings, oil-burner equipment, kitchen appliances, and automatic time recorders.

The hardware industry finds zinc castings indispensable for bathroom and plumbing fixtures, venetian-blind hardware, furniture hardware, padlocks and other locking devices, bicycle parts, refrigerator hardware, waste-food disposal equipment, highway markers, and safety signs.

General industrial equipment made of zinc castings includes such items as pulleys, couplings, mandrels, bearings, hoists, gears, printing-press parts, paint sprayers, and oil pumps.

Some uses exist, however, to which zinc die castings cannot be applied. For example, they cannot be used when the temperature of the part in service will exceed 200°F. They also have low impact strength below 0°F. Other factors that must be considered in the utilization of zinc alloys are their low creep strength and relatively high expansivity.

Creep is defined as the continuous deformation of metals under steady load. Such metals as steel, iron, nickel, and copper exhibit this property only at elevated temperatures, while others, such as lead, tin, and zinc, will flow at room temperature under loading. Zinc and zinc alloys do not have any recognized modulus of elasticity. They flow under continuously applied loads at room temperature and to a greater extent with increase in temperature. For any structural use, therefore, it is important that this property be given careful attention by the designer of the equipment in which zinc-alloy die castings are contemplated. He must consider a range of working stresses depending upon the load to which the part may be continuously subject and upon the amount of deformation that can be permitted.

The New Jersey Zinc Company has conducted creep tests on zinc and zinc alloys over a number of years to determine values for the permissible stress of zinc die-cast parts. The reader is referred to the work of Kelton, Grissinger, and Ruzicka.[18,19,20]

ALUMINUM-BASE ALLOYS

The outstanding characteristic of aluminum is, of course, its lightness, and this is one of the principal factors that has increased its use as a die-casting material. Other salient features that make it adaptable for die-cast parts are

1. Retention of a high polish for long periods of time.
2. Excellent corrosion resistance.
3. Freedom from dimensional changes.
4. Retention of properties at subnormal temperatures.
5. High thermal and electrical conductivity.

The ability of a part to take and hold a polished luster is very important. Advantage is taken of this property in the finishing of many

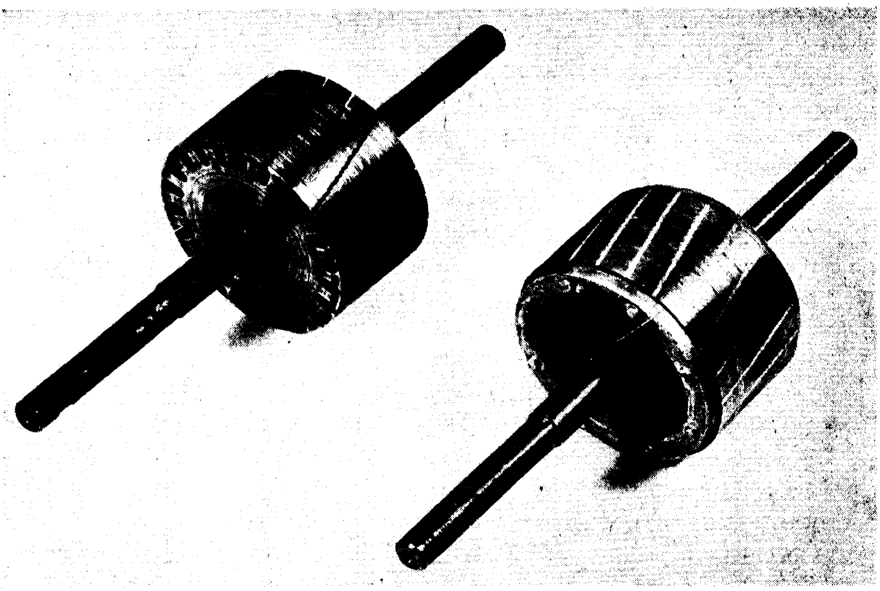


FIG. 7.9. Rotor for small electrical motor. Aluminum is die-cast around the lamination and shaft assembly, left, to form a complete rotor, right.

aluminum die castings, especially household utility parts, by simply polishing the casting. The result is a highly decorative finish produced at a low cost. The binary magnesium-aluminum types of alloys containing from 4 to 10 per cent magnesium are superior to other types of aluminum-base alloys in this respect, since they are capable of being polished to a whiter and more highly lustrous finish.

The corrosion resistance of aluminum die castings in the as-cast condition is excellent. When it is necessary to increase resistance to attack by corrosion media, the anodic oxidation treatment can be used, which greatly enhances corrosion resistance even in salt atmospheres. Here again, the aluminum-magnesium alloys excel over other alloys, particularly where decorative effects through anodizing are desired. All alumi-

num alloys are capable of being anodized, however; this subject is discussed further in Chap. 8, Finishing of Die Castings.

Aluminum die castings are remarkably stable and are not subject to changes of dimensions or properties on aging. However, whenever it is required to hold to extremely close machined dimensions, on the order of 0.0001 in., for example, it may be expedient to anneal the die castings prior to the machining operations. This heat-treatment relieves any residual casting stresses set up as a result of the rapid chilling of the liquid metal. A simple anneal at 400°F for about 1 hr is usually sufficient to accomplish complete stability.

Another advantage of aluminum is that it is capable of withstanding extremely low temperatures without a material change in ductility. For this reason, it has found extensive use in aircraft, refrigerators, and similar equipment where temperatures as low as 60°F may be met.

Finally, the electrical conductivity of aluminum is second only to copper and some of the precious metals. As a result, it is used extensively in the electrical industry, one application being the die casting of rotors for some of the smaller sized electrical motors (Fig. 7.9).

Metallurgy of Aluminum-base Alloys. The composition and properties of common aluminum-base die-casting alloys are given in Table 7.9. Note that all these alloys, with the exception of the 5 per cent silicon and the 8 per cent magnesium alloys, have a maximum iron content of 1.3 per cent. In some specifications, notably ASTM, the same alloys are also shown with allowable iron of 2.0 per cent maximum. A high iron content is specified primarily for the production of castings by the air-gooseneck type of casting machine, because with this machine the problem of control of iron pickup in the alloy is always present. However, an iron content of 2.0 per cent is neither desirable nor necessary with the cold-chamber type of casting machine, which has almost wholly displaced the gooseneck machine in the production of aluminum die castings. Iron contents in the high range approaching 2.0 per cent cause brittleness, low shock resistance, and poor machinability, especially in connection with high silicon contents.

On the other hand, iron appreciably below 1.0 per cent may cause some casting difficulty because it creates a tendency in the alloy to weld or solder to steel die surfaces and thereby causes the galling of cores, slides, and other movable die parts. An optimum iron content of 1.0 per cent with a maximum of 1.3 per cent is both practicable and productive of the best casting results in the cold-chamber type of machine, since it does not materially affect ductility and shock resistance in the castings.

TABLE 7.9. COMPOSITION AND PROPERTIES OF ALUMINUM DIE-CASTING ALLOYS *

	Alloy specification					
Doehler-Jarvis Corporation	Alsiloy 5	Alsiloy 1	Alsiloy 3	Alsiloy 9	Alsiloy 10	Alumin 8
Aluminum Company of America	43	13	85	A380	360	218
SAE	304	305				
ASTM B85-46T	S4	S9	SC5	SC6	SG2	
Alloy composition, per cent						
Copper	0.6 max	0.6 max	3.0 to 4.0	3.0 to 4.0	0.6 max	0.20 max
Silicon	4.5 to 6.0	11.0 to 13.0	4.5 to 5.5	7.5 to 9.5	9.0 to 10.0	0.50 max
Iron	2.0 max	1.3 max	1.3 max	1.3 max	1.3 max	1.8 max
Magnesium	0.1 max	0.1 max	0.1 max	0.1 max	0.4 to 0.6	7.5 to 8.5
Manganese	0.3 max	0.3 max	0.5 max	0.5 max	0.3 max	0.3 max
Zinc	0.5 max	0.5 max	0.6 max	0.6 max	0.5 max	0.1 max
Nickel	0.5 max	0.5 max	0.5 max	0.5 max	0.5 max	0.1 max
Tin	0.1 max	0.1 max	0.3 max	0.3 max	0.1 max	0.1 max
Other elements	0.2 max	0.2 max	0.5 max	0.5 max	0.2 max	0.1 max
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder
Typical physical properties						
Tensile strength,† psi	30,000	39,000	40,000	46,000	41,000	45,000
Yield strength (0.2 per cent set), psi	16,000	21,000	24,000	25,000	23,000	27,000
Elongation in 2 in., per cent	5.0	2.0	3.5	3.0	5.0	8.0
Charpy impact,‡ ft-lb	4.0	2.0	3.0	3.0	5.0	7.0
Specific gravity	2.70	2.66	2.77	2.76	2.68	2.55
Weight per cu in., lb	0.097	0.096	0.100	0.099	0.097	0.092
Shear strength, psi	22,000	25,000	23,000	29,000	28,000	30,000
Melting point, °F	1150	1065	1140	1085	1100	1140
Thermal conductivity, cgs units	0.38	0.37	0.29	0.29	0.36	0.25
Thermal expansion, in./in./°F	0.0000122	0.0000111	0.0000116	0.0000111	0.0000116	0.0000133
Electrical conductivity, per cent of copper standard	41	37	28	27	37	25
Brinell hardness	50	80	75	80	75	80
Endurance limit, psi §	17,000	19,000	22,000	19,000	18,000	23,000

* The properties are typical of those obtained from die-cast tension- and impact-test specimens in accordance with ASTM B85-46T.

† Tensile properties are average values obtained from a ¼-in.-diameter ASTM test specimen cast in a high-pressure, cold-chamber, die-casting machine.

‡ Charpy impact specimens, die-cast ¼- by ¼-in. bars.

§ R. R. Moore type of specimen, 500 million cycles.

An iron content higher than 1.3 per cent is necessary in the 5 per cent silicon and 8 per cent magnesium alloys to offset their tendency to solder to the die. The aluminum-iron phase diagram is shown in Fig. 7.10.

Other metals, namely, zinc, copper, silicon, nickel, magnesium, tin, lead, and bismuth, also affect the properties and castability of aluminum-base materials in the following way:

Zinc. The prime effect of additions of zinc to aluminum die-casting alloys is to cause hot-shortness and a tendency of the castings to crack.

Zinc is present only as an impurity in some secondary aluminum alloys and seldom, if ever, is it added intentionally as a constituent. Zinc should preferably be kept below 1.0 per cent in most aluminum die-casting alloys. With increasing zinc content, fluidity of the alloy is increased,

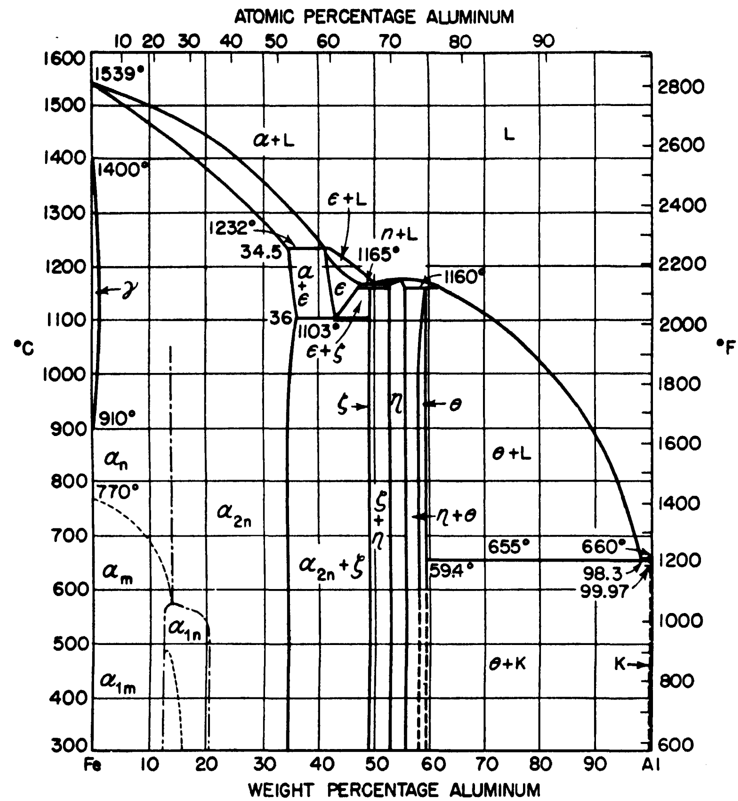


FIG. 7.10. Aluminum-iron phase diagram. The limit of solubility of iron in aluminum is very low—about 0.03 per cent at the eutectic temperature at 1250°F; at lower temperatures, this limit decreases.

The θ phase in accompanying diagram has the composition corresponding with the formula $FeAl_3$.

but the hot strength is proportionately decreased and the shrinkage is increased—all of which has an adverse effect on castability. The aluminum-zinc phase diagram is shown in Fig. 7.11.

Copper. With increasing copper content in aluminum, the fluidity, tensile strength, and hardness are correspondingly increased, while shrinkage, ductility, hot-shortness, and corrosion resistance are uniformly reduced. Binary copper-aluminum alloys with copper up to 10

per cent have been used in the past for die casting, but such alloys have been wholly replaced by the straight silicon-aluminum types or copper-silicon alloys having about 4 per cent copper and 5 to 9 per cent silicon. The latter type of alloys have superior casting qualities.

Silicon. Silicon is one of the most important elements to aluminum-base die-casting alloys. Silicon up to 12 per cent promotes high fluidity, high hot strength, and freedom from hot-shortness. Binary silicon-

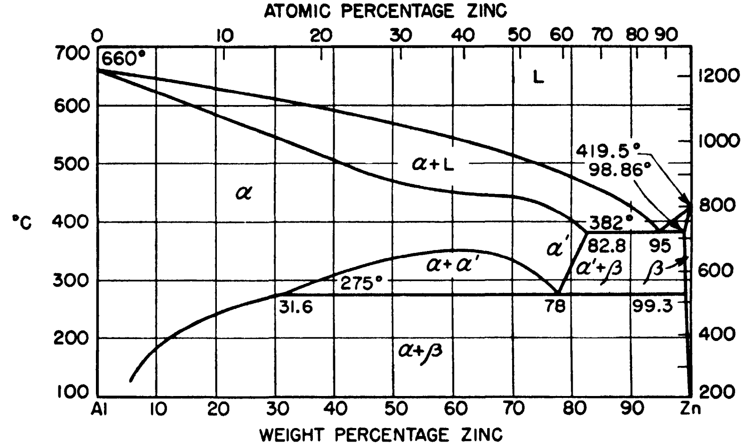


FIG. 7.11. Zinc-aluminum alloy system. Slightly less than 1 per cent of aluminum enters into solid solution with zinc to form a homogeneous alloy consisting of a single phase known as the alpha phase. Zinc added to aluminum in amounts up to about 20 per cent enters into solid solution to form a homogeneous alloy—the gamma phase. Zinc alloys containing 1 to 21 per cent aluminum between the freezing point and 518°F (270°C) consist of a eutectic of alpha and a new phase or constituent known as beta, together with an excess of alpha if the aluminum content is less than 5 per cent, or of beta if the aluminum content is above 5 per cent.

aluminum alloys possess excellent corrosion resistance, high heat conductivity, good electrical conductivity, low expansivity, and low specific gravity; they do possess somewhat poorer machining characteristics than the copper-silicon and binary magnesium alloys, but the latter properties are of secondary importance in many applications compared to their desirable properties. Consequently, silicon often is added in small amounts to aluminum alloys not containing it to reduce hot-shortness and to prevent cracking. Phase diagrams of alloys of aluminum and silicon are shown in Figs. 7.12 and 7.13.

Nickel. Nickel in moderate percentages in aluminum alloys tends to increase strength and hardness in much the same manner as does copper. It generally improves the surface finish of the casting by imparting to it

a high polished luster and high light reflectivity. It has a tendency to reduce the adverse effects of high iron contents in the alloy. Like copper, nickel adversely affects corrosion resistance. However, nickel often is used in alloys requiring high strength and hardness at elevated temperatures, in which case the corrosion resistance is of secondary importance.

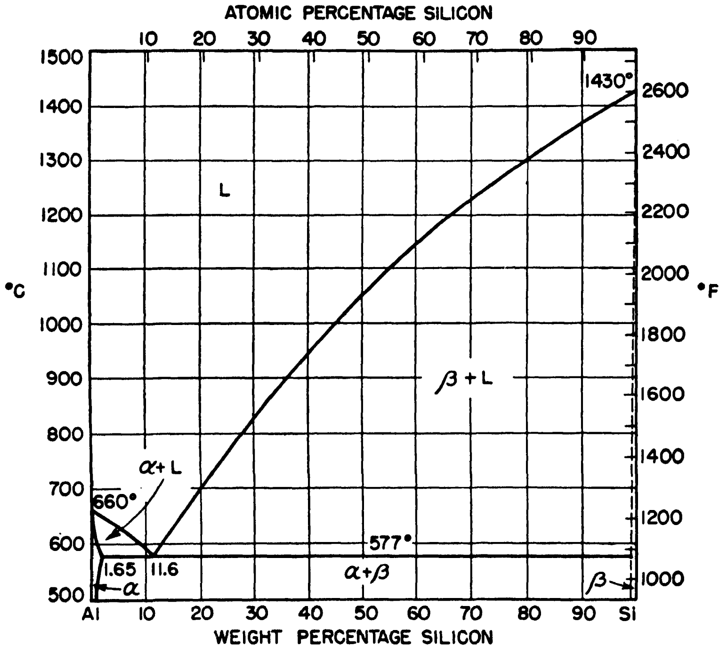


FIG. 7.12. Aluminum-silicon phase diagram. The solubility of silicon in aluminum is very low. At a temperature of 1020°F the solubility is 1.30 per cent and only 0.05 per cent at 400°F. The alloy containing 11.6 per cent silicon solidifies as the eutectic at 1072.4°F (578°C). This is the composition of the normal eutectic. When the alloy is "modified" the eutectic is displaced slightly to the right, the modified at about 14 per cent silicon being at 1043.6°F (564°C).

Magnesium. The binary aluminum-magnesium alloys possess good physical properties in the die-cast state. Alloys with up to 8 per cent magnesium have excellent resistance to corrosion and adaptability to anodic oxide coatings. They take on a high, white, lustrous polish having good light reflectivity. They are the easiest to machine of all the aluminum die-casting alloys and are lighter than pure aluminum in weight. However, aluminum-magnesium alloys have comparatively poor casting qualities; since their strength and ductility at elevated temperatures are relatively low and their shrinkage on cooling is high, they are difficult to cast in anything but the simplest of shapes. Unlike other

aluminum alloys, particular care in the handling of the aluminum-magnesium alloys in the molten state must be exercised, since there is a tendency toward excessive oxidation of the melt and the progressive loss of magnesium. The aluminum-magnesium phase diagram is shown in Fig. 7.14.

Tin. Tin in aluminum alloys tends to reduce strength at elevated and at room temperatures. It increases hot-shortness when present in

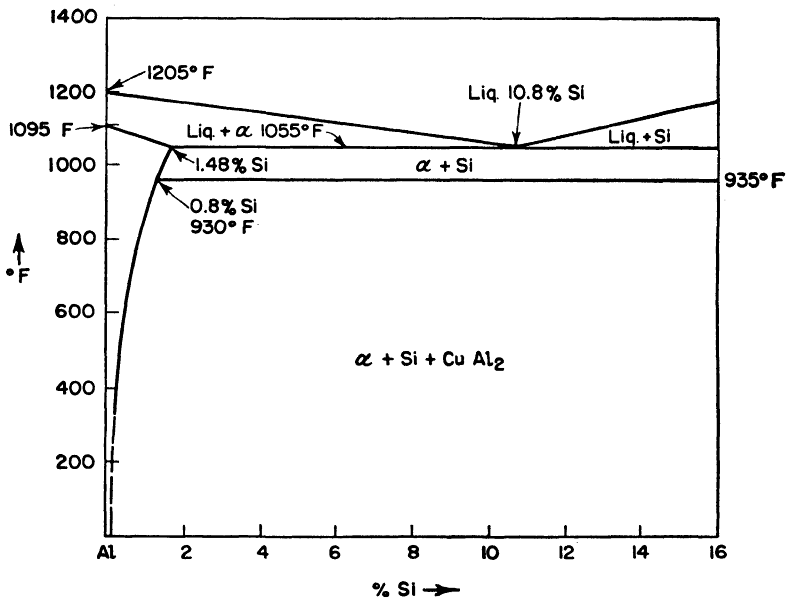


FIG. 7.13. Aluminum-copper-silicon ternary diagram. Only that part of the ternary aluminum-copper-silicon equilibrium diagram which is of interest to the die caster—4 per cent copper—is shown here. (MONDOLFO, L. F., Metallography of Aluminum Alloys.)

amounts of 0.5 to 1.0 per cent and, being cathodic to aluminum, affects corrosion resistance adversely. However, tin is an important constituent in aluminum alloys that are used for bearings. Except as an impurity in secondary alloys, tin seldom is met with in aluminum die casting.

Lead and Bismuth. Neither of these elements is frequently encountered in aluminum die-casting alloys, but both are used in free-cutting alloys of the copper-aluminum type. Both are cathodic to aluminum and therefore decrease somewhat the corrosion resistance of the base material.

Comparison of Aluminum-base Alloys. With this background on the effect of the various elements on aluminum-base die castings, it is easier

to compare the common types of aluminum-base alloys. In addition to the summary given in Table 7.10 the following analysis can be made:

The *12 per cent silicon-aluminum alloy* has long been one of the best aluminum alloys for the die casting of large and intricate parts and parts having thin-walled sections. It possesses excellent casting qualities because of its superior fluidity and freedom from hot-shortness. Other advantages are its excellent corrosion resistance, low thermal expansion, high heat and electrical conductivity, and low specific gravity.

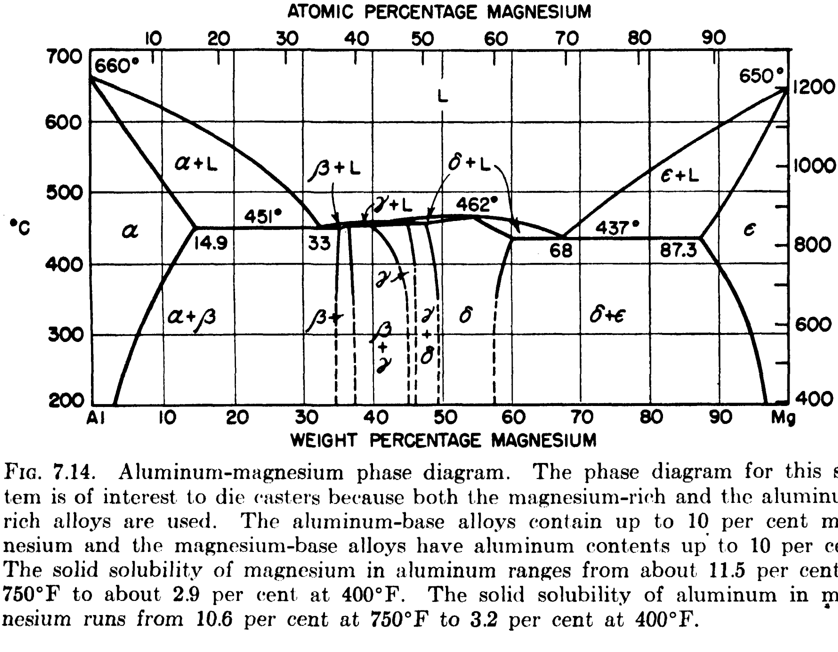


FIG. 7.14. Aluminum-magnesium phase diagram. The phase diagram for this system is of interest to die casters because both the magnesium-rich and the aluminum-rich alloys are used. The aluminum-base alloys contain up to 10 per cent magnesium and the magnesium-base alloys have aluminum contents up to 10 per cent. The solid solubility of magnesium in aluminum ranges from about 11.5 per cent at 750°F to about 2.9 per cent at 400°F. The solid solubility of aluminum in magnesium runs from 10.6 per cent at 750°F to 3.2 per cent at 400°F.

For maximum corrosion resistance, the copper content should be kept below the 0.60 per cent maximum allowed by the specifications. The iron content should be maintained at an optimum of about 1.0 per cent for best results, since ductility is proportionately decreased with an increase in iron content.

The *10 per cent silicon–0.5 per cent magnesium alloy* is similar to the 12 per cent silicon alloy in castability and corrosion resistance, but possesses better mechanical properties, as shown in Table 7.9. Thus, it can readily replace the regular binary 12 per cent silicon alloy when the utmost in strength, ductility, and resistance to impact is required.

The *9 per cent silicon–4 per cent copper alloy* is a general-purpose secondary alloy that was developed during World War II. It originally

was derived from aircraft aluminum scrap, most of which contained about 4 per cent copper. When the magnesium in the scrap was removed and up to 9 per cent silicon was added, the resultant alloy proved extremely suitable for die casting and is now being used in large quantities.

TABLE 7.10. RELATIVE CASTING CHARACTERISTICS OF ALUMINUM DIE-CASTING ALLOYS

Alloy, ASTM designation	Nominal composition, per cent	Casting characteristics *				
		Fluidity	Hot-shortness	Casta-bility	Shrink-age	Strength at elevated tempera-tures
S4	5 silicon	3	1	3	2	2
S9	12 silicon	1	1	1	1	1
SC5	5 silicon 4 copper	3	3	3	2	2
SC6	9 silicon 4 copper	2	2	2	2	2
SG2	10 silicon 0.5 magnesium	1	1	1	1	1
218 (Alcoa)	8 magnesium	4	4	4	3	3

* In order of utility, 1 being the highest rating.

It possesses excellent casting characteristics and good physical properties. Because of its copper content, however, it is somewhat inferior to the copper-free alloys in surface corrosion resistance. While it stands up fairly well under ordinary atmospheric weathering, it must be painted or otherwise protected when exposed to severely corrosive atmospheres.

The *5 per cent silicon-aluminum alloy* is used for die castings only because of its relative softness and ductility. It is used primarily for die-cast parts that must be subsequently formed, shaped, or worked after casting to facilitate assembly to other parts. It is difficult to die-cast compared to the other standard alloys of aluminum. It has a tendency to "weld" or "solder" to steel die surfaces, although this tendency may

be partly overcome by increasing the iron content to 1.50 per cent or more.

The tensile properties of this alloy are the lowest of all the standard die-casting alloys, and its machinability is poor due to the tendency of tools to drag over its surfaces. Its corrosion resistance is good; but when the maximum in corrosion resistance is required, the percentage of copper, nickel, and other impurities must be held to a minimum value.

The *8 per cent magnesium-aluminum alloy* is essentially a binary magnesium-aluminum alloy. Although somewhat more difficult to die-cast than the other standard alloys, it possesses certain characteristics that merit its use for many applications. It has excellent corrosion resistance and good physical properties—especially a high impact strength. It takes a high, white lustrous polish; has good machinability; and is capable of taking anodizing and coloring treatments better than the other aluminum alloys.

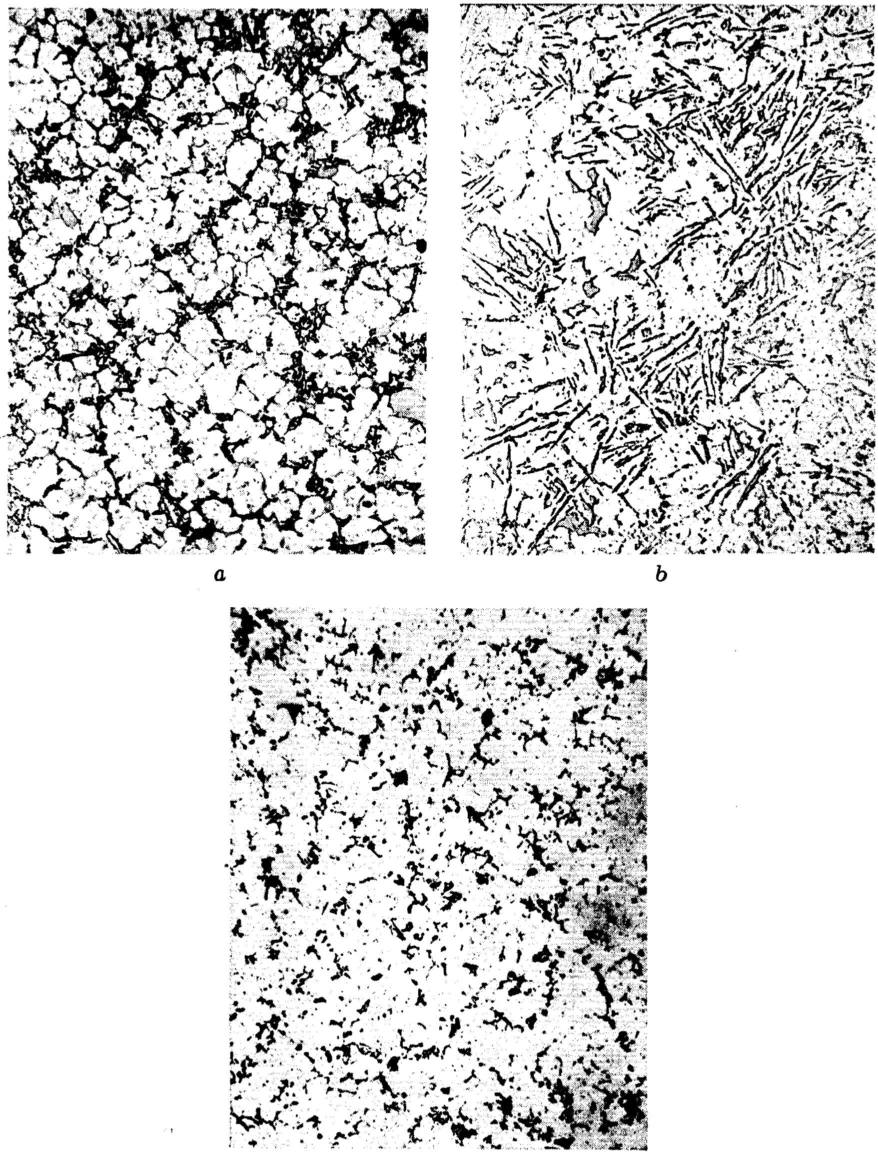
The microstructures of some of the various alloys of aluminum are shown in Fig. 7.15.

Melting Furnaces for Aluminum-base Alloys. A number of types of furnace are in regular use for the melting of aluminum and its alloys: (1) an *open-hearth* or *reverberatory type,* in which the metal is melted by the radiation of heat from the roof and walls of the furnace, which are not in contact with the metal; (2) *pot furnaces,* in which the metal is melted out of contact with the source of heat; and (3) *induction-heated furnaces,* in which the heating is done by induced electric current within the metal being melted.

The *reverberatory furnace* (Figs. 7.16 and 7.17) is the most commonly used type for melting aluminum alloys because of its ability to melt large charges at the lowest cost. Capacities of this type of furnace may run from 1,000 to 50,000 lb, but intermediate sizes of from 5,000 to 10,000 lb capacity are generally used. The small units of 1,000 lb capacity are generally placed near the casting machines to hold the molten alloys in place of the iron pot furnaces formerly used for this purpose. Large 50,000-lb types are used for the melting of large batches of metal chiefly by smelters or metal suppliers.

Rotary barrel furnaces are refractory-lined shells mounted horizontally on trunnions and fired from either end by gas or fuel oil. They are also in the class of direct-heat furnaces. While not so efficient as reverberatory furnaces, these units often are utilized for preparing or melting down special small heats of alloys. The capacities of this type are, for the most part, on the order of 1,000 to 1,500 lb, although some are available having capacities up to 20,000 lb.

Some limited use has been made of radiant heating in direct-heat fur-



a b c

FIG. 7.15. Photomicrographs of three standard aluminum pressure die-cast alloys. *a,* Alloy SC6: 4 per cent copper, 9 per cent silicon; *b,* alloy S9: 12 per cent silicon; and *c,* alloy 218: 8 per cent magnesium. All three are at 500× and etched as follows: 1 per cent caustic soda in water, swabbed 10 sec; and 0.5 per cent hydrofluoric acid in water, swabbed 2 sec.

naces. Heating by this means is said to have low efficiency primarily because of the high reflectivity of aluminum; this results in slower heating and consequent higher melting costs.

Stationary or *tilting-type pot furnaces* represent the indirect-heating class of furnaces. These furnaces are made up of a refractory-lined shell into which an iron pot is inserted. Sufficient combustion space is allowed

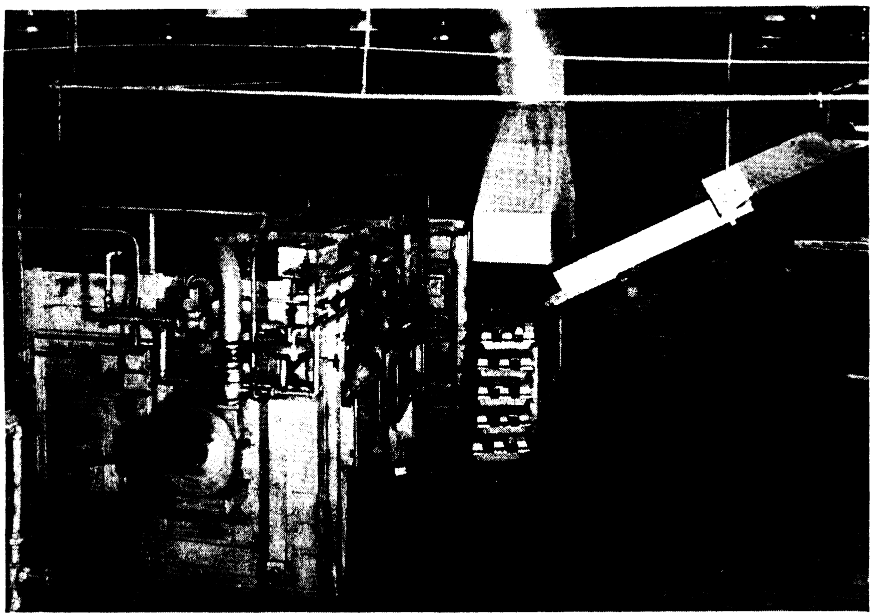


FIG. 7.16. Closed-end reverberatory furnace (foreground) and open-end reverberatory furnace (background) for melting of aluminum alloys.

between the refractory and the outside walls of the iron pot to promote efficient heating. Gas or oil can be used for fuel. Because of the need for controlling iron pickup in the aluminum alloy when melting is done in iron pots, considerable attention must be given to the proper coating of the iron pots to minimize such action.

In addition to its use for melting aluminum, this type of furnace also may be used for the holding of molten aluminum alloys at the casting machines. Due to the maintenance difficulties associated with iron pots, however, they are gradually being replaced by refractory furnaces even for simple casting-machine holding pots.

Electric furnaces of the high-frequency-induction type, which are being used to a considerable extent for melting copper alloys and steel, are not used for aluminum alloys mainly because of high initial first cost and

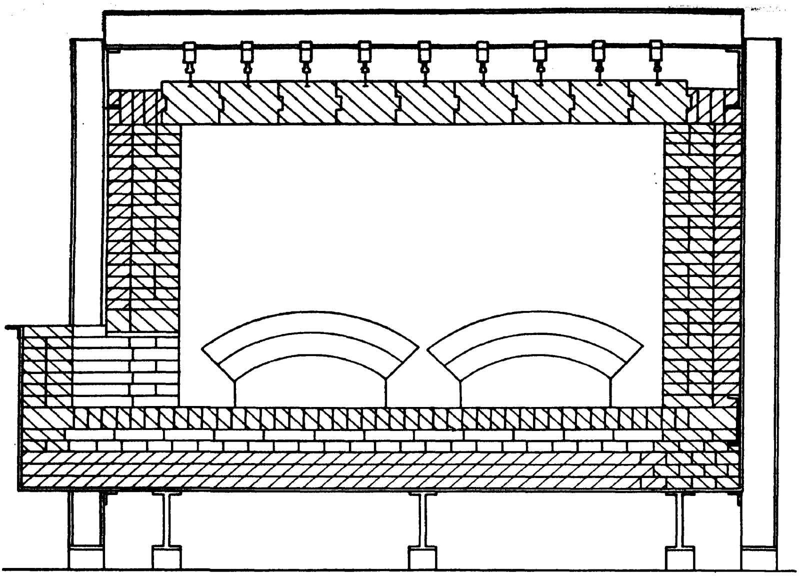
high power cost. Low-frequency-induction melting equipment is gaining in use for melting and holding aluminum alloys, because new and improved furnace designs have overcome former difficulties and reduced equipment cost considerably.

The method of melting aluminum in electric induction furnaces in which the heating is done within the metal itself provides several advantages not obtained with other methods. First, there is the absence of

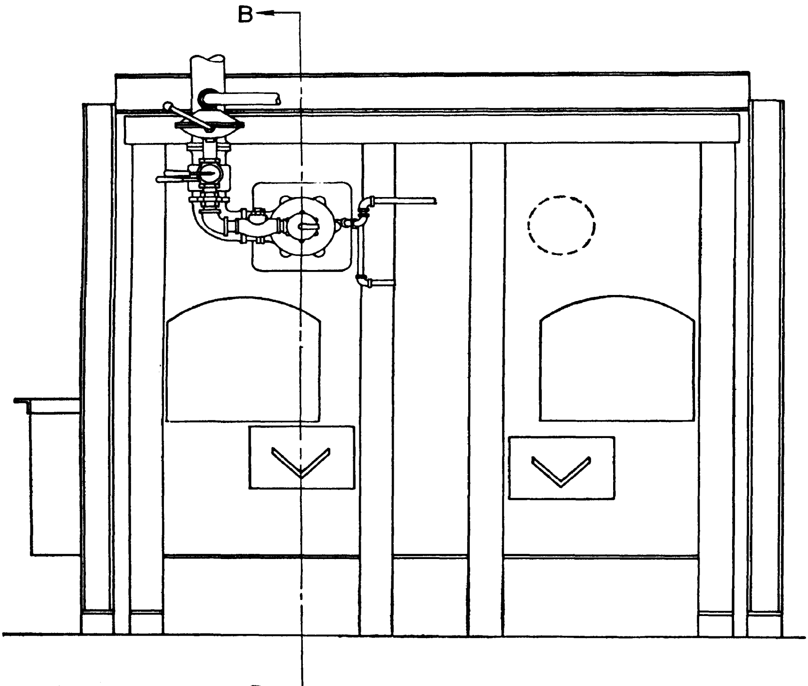
FIG. 7.17. Reverberatory holding furnaces in the die-casting department of a large plant. Furnaces of this type are built in a wide range of sizes.

any combustion products, which promote clean metal and absence of gas porosity. Second, the metal is continually circulated by the magnetic field, which ensures uniformity of composition and prevents segregation of alloy constituents. Finally, due to lack of external heating, the surroundings and operating conditions are cooler.

Against these advantages, there are some disadvantages or limitations that must be considered. The high initial and operating costs of electric induction equipment, compared with the costs of other types of melting equipment, now prohibit their general use for melting aluminum. Other factors, such as the need for frequent cleaning of the heating channels (caused by the precipitation of sludge and build-up of oxides from certain types of alloys) and the necessity of keeping the metal in the molten state continuously, also contribute toward their present limited use.



SECTION A-A
Sectional view



Front view

FIG. 7.18. Construction details of a reverberatory furnace.

These limitations, however, may be nullified in the future, and a greater application made of such furnaces for the handling of aluminum alloys.

Melting and Casting Procedures for Aluminum-base Alloys. As just mentioned, gas-fired reverberatory-type furnaces are the most widely used type for melting aluminum alloys. The walls of these furnaces consist of a welded steel shell, 1 in. of flake mica insulation next to the

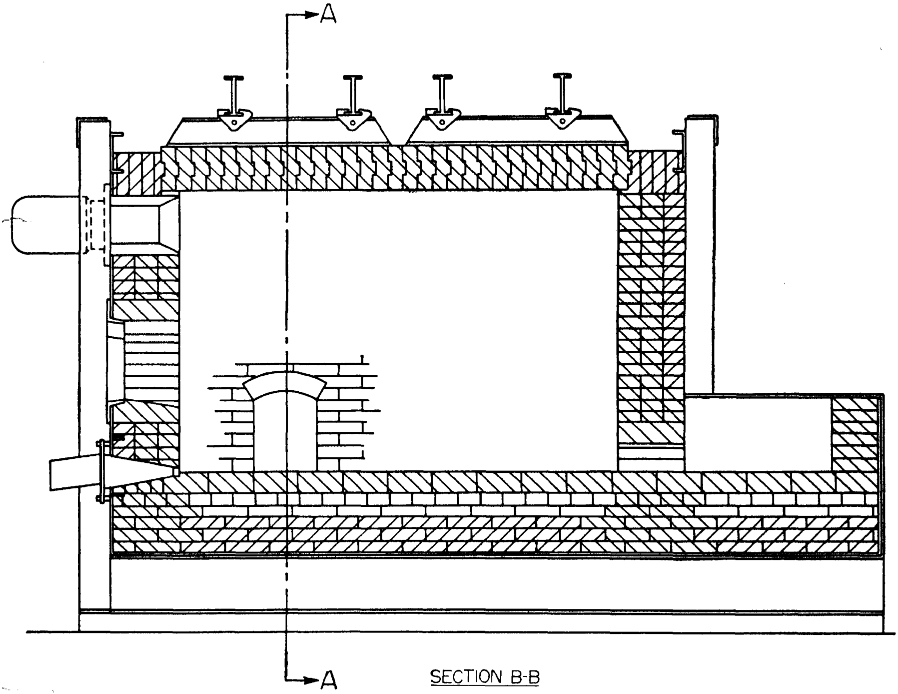


FIG. 7.19. Sectional side view of reverberatory furnace.

shell, 9 in. of insulating brick, and $4\frac{1}{2}$ in. of firebrick (Figs. 7.18 and 7.19). The roof has a built-in arch and is insulated with 9 in. of insulating brick. They are built in two sections which are separated by a wall of firebrick that extends from the bottom of the furnace to the roof. Two arch openings are built in the bottom of this wall to permit passage of molten metal from one section to the other.

One of these sections is the loading side, into which all ingot and scrap metal are fed for melting, whereas the other section is a holding reservoir in which the molten metal lies quiet and dormant, refining itself by precipitation of the insolubles and sludge and by boiling out the gases.

Metal to be delivered from the casting machine is tapped from the

holding side of the furnace by knocking out the hole plug and permitting the molten metal to flow from the tap hole into a bull ladle. When the bull ladle is filled, the flow of metal from the tapped hole is stopped by plugging it with a moist, plastic clay plug composed of sand and fire clay.

All dross on the surface of the metal is skimmed by means of a perforated hand ladle, and the metal is then delivered to the casting-machine holding furnace.

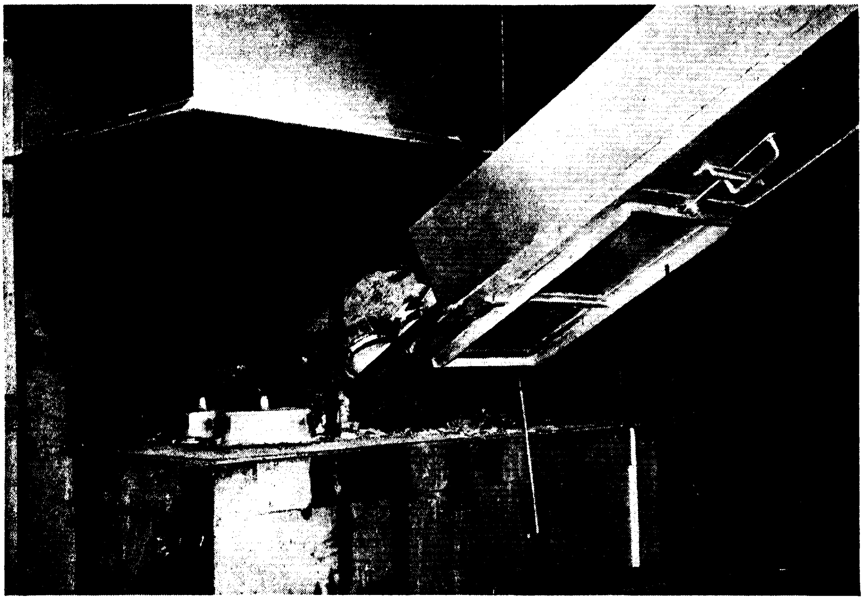


FIG. 7.20. Charging an open-end reverberatory furnace with scrap from the casting department. All furnaces are charged with regulated portions of scrap and ingot in definite-sized batches.

The melting furnaces are charged with ingot and scrap in regulated proportions and in definite-sized batches (Fig. 7.20). They are not tapped until the metal temperature of the furnace reaches the point set by the automatic temperature-control equipment—generally 1250°F. A furnace of 8,000 to 10,000 lb capacity has a melting rate of approximately 1,500 lb/hr on the basis of full temperature recovery. On the basis of continuous melting without full temperature recovery, these furnaces are capable of 2,400 lb/hr.

The furnaces should not be forced beyond their normal melting capacity, however, and the metal should not be tapped after loading until the temperature setting of the furnace is again reached. Large fluctua-

tions in the temperature of the metal delivered to the casting-machine pots seriously interfere with the production of good castings.

In normal melting, the furnaces are fluxed off every 2 hr on the charging side, and every 4 hr on the holding side. *Fluxing* is the application of a solid or gaseous material to molten metal and alloys to remove oxides, gas, and foreign occlusions from the metals. In the melting down of virgin metals, it may not always be necessary to employ fluxes. However, fluxes should be used when the charge contains appreciable scrap or secondary metals, because they function to separate the oxides and other nonmetallic compounds from the metal, to remove foreign matter and inclusions, and to remove absorbed gases.

Fluxes used for aluminum may be either solid or gaseous. The solid fluxes are made of mixtures of volatile chlorides, fluorides, or stable metallic salts, some of the compositions of which are as follows:

1. 50 per cent sodium chloride, 25 per cent sodium fluoride, 25 per cent potassium chloride.
2. 50 per cent sodium chloride, 25 per cent sodium silicofluoride, 25 per cent potassium chloride.
3. 85 per cent sodium silicofluoride, 5 per cent potassium chloride, 5 per cent sodium chloride, 5 per cent cryolite.
4. 40 per cent potassium chloride, 30 per cent sodium chloride, 15 per cent calcium carbonate, 15 per cent sodium fluoride, 2 per cent cryolite (optional).
5. 50 per cent potassium chloride, 50 per cent cryolite.
6. 30 per cent potassium chloride, 70 per cent cryolite.
7. Potassium fluoborate.
8. 5 per cent potassium fluoborate, 95 per cent No. 310 Dow flux.
9. Zinc chloride.
10. Aluminum chloride.

The gaseous fluxes most commonly used for aluminum alloys are nitrogen, helium, and chlorine.

The operation of fluxing must be carefully executed. The solid salt fluxes must be dry and applied to the melt in such a way as to react with the largest area of metal possible. The metal should be at the temperature recommended for the flux being used so that it reacts readily to produce the desired type of dross. In the melting of fine scrap materials, it is desirable first to sprinkle some flux over the solid metal just as it is charged into the furnace. The amount of flux required will depend upon the type of materials being melted, varying with the amount of scrap materials present. The amount required can be determined by adding a small quantity of flux to the molten alloy, stirring it in, and continuing

to stir in small amounts until the dross becomes powdery and dry. Then the dross can be readily removed from the surface of the melt without removing any appreciable amount of metal along with it.

The amount of dross formed also will depend upon the character of the metal being melted. With new or virgin metal very little dross or skimmings are formed, while a considerable amount may be formed if the scrap content is large and dirty. If large amounts of dross are formed, it is essential that they be removed before the addition of other metal.

Gaseous fluxes are especially useful for removing gas absorbed into the molten metal through overheating at high melting temperatures.

These fluxes are usually applied to the molten metal by means of a refractory pipe or tube, which is submerged deep into the metal—preferably to the bottom. The gas is allowed to bubble slowly through the metal for the time necessary to obtain the desired results. The gases must be dry and free from water vapor.

Although chlorine is the most effective gaseous flux for aluminum, it is highly toxic and precautions must be taken to ensure its removal from the atmosphere surrounding the furnaces. Nitrogen and helium, being inert and nontoxic, do not require special ventilation at the furnace.

Boron trichloride is a gaseous flux that also has had some use for certain types of aluminum alloys, particularly those with a relatively high magnesium content. It is, however, much more expensive than the other gases and its use must be justified by results not obtainable with the regular gases.

If the flux is solid, it is mixed into the melt with the skimmings on the surface of the metal by raking the flux and skims back and forth across the surface. After the flux and skimmings have been thoroughly mixed, they are allowed to lie dormant until the thermic reaction is completed. The completion of this can be noted by the dry powdery condition of the dross and its lack of tackiness.

The dross is then raked from the furnace into a dross buggy with as little disturbance of the metal as possible. This dross buggy consists of a cast-iron hemisphere about 20 in. in diameter that is mounted on two steel wheels; in the bottom of the hemisphere is a 1-in. drain hole.

The dross in the buggy is vigorously stirred by means of an iron rod to liberate any pockets of trapped molten metal and to facilitate draining off this free metal into a mold beneath the buggy. The dross then is dumped onto a water-cooled plate and sprayed with water to check the exothermic reaction set up between the fine metal globules of the dross and the flux. This operation prevents the complete oxidation of the metals in the dross.

The dross finally is pushed into a rotary drum cooler, where it is

further cooled to prevent the regeneration of the thermic reaction and to condition the dross for easier screening and recovery of the metallic elements.

Common practice is to deliver the molten aluminum alloy to the casting-machine furnaces by means of electrically operated bull ladles holding about 450 lb of molten alloy. These bull ladles can be pushed by the metal tenders along overhead electrified rails, and the ladles can be raised or lowered by means of an electric hoist. The ladle bowls are constructed with a sheet-iron shell lined with $1\frac{1}{2}$ in. of fire clay and are tilted by means of hand-operated worm and worm gears. Each ladle should be used exclusively for one particular alloy and should be marked so that there is no mixing of metals through interchange of ladles.

In one large die-casting plant, the metal is poured from the bull ladles into the back filling well of the casting-machine furnaces. These furnaces, which are of the reverberatory type and have a capacity of 1,000 lb, are constructed with a steel outer shell, one layer of insulating brick, and one layer of firebrick. A filling well is built onto the back of the furnace and a ladling well is built onto the front. There is a clean-out door in the side of the furnace and a tap hole in the bottom to permit complete drainage.

Each furnace is marked with the machine number and a changeable metallic tag indicating to the metal tender the alloy to be used.

These tags are placed on the casting-machine furnaces by the casting-department supervisor from instructions obtained from job records. A list of all jobs running on each casting machine is given to the laboratory and melting-department foreman at the start of each shift. The laboratory checks the lists with the laboratory record to see that no error has been made in the job record.

The laboratory secures samples from each casting-machine furnace every 4 hr and runs a complete spectroscopic analysis on each sample. This check is to ensure that the right alloy is being used on each job and that no contamination has occurred that will throw the composition of the metal outside of specification limits. In addition, each melting furnace is checked every 2 hr by means of a complete spectrographic analysis to ensure that the alloy being drawn from the furnace is up to specifications.

Applications of Aluminum Die Castings. Aluminum-base die castings are widely used in household appliances, optical equipment, electrical equipment, motor vehicles, and miscellaneous machine parts (Fig. 7.21).

In the household-appliance field, aluminum die castings are extensively used for component parts of vacuum cleaners, sewing machines, washing

machines, ironers, food mixers, dishwashers, radios, television receivers, record players, cooking utensils, and refrigerators.

The tonnage of aluminum-base die castings for automotive usage is rather limited at present when compared with the tonnage of zinc-base die castings that is used. There are some interesting new applications,

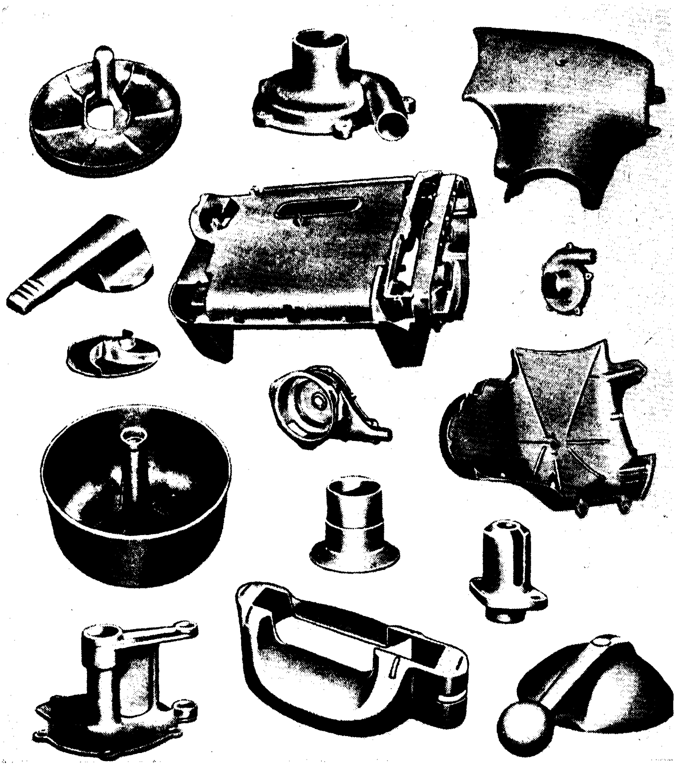


FIG. 7.21. Die-cast aluminum parts for household washing machines.

however, which may indicate a trend toward an increase of aluminum die castings in this field. One example is the use of aluminum die castings for the valve mechanism in the General Motors Hydra-Matic transmission. These parts are so complex in design that it has been found impossible to produce them in any manner other than die casting without resorting to exorbitant tooling costs. Similar types of valve-control mechanisms are being developed, and there are a number of other automotive uses that utilize the particular properties which aluminum die castings have to offer.

The optical industry relies on aluminum die castings for cameras, pro-

jectors, binoculars, microscopes, and similar equipment. The electrical industry finds aluminum die castings advantageous for fans, impellers, motor end bells, motor housings and rotors, and electric drills. In the office-, store-, and factory-appliance and business-machine lines, aluminum die castings are utilized in adding machines, typewriters, dicta-

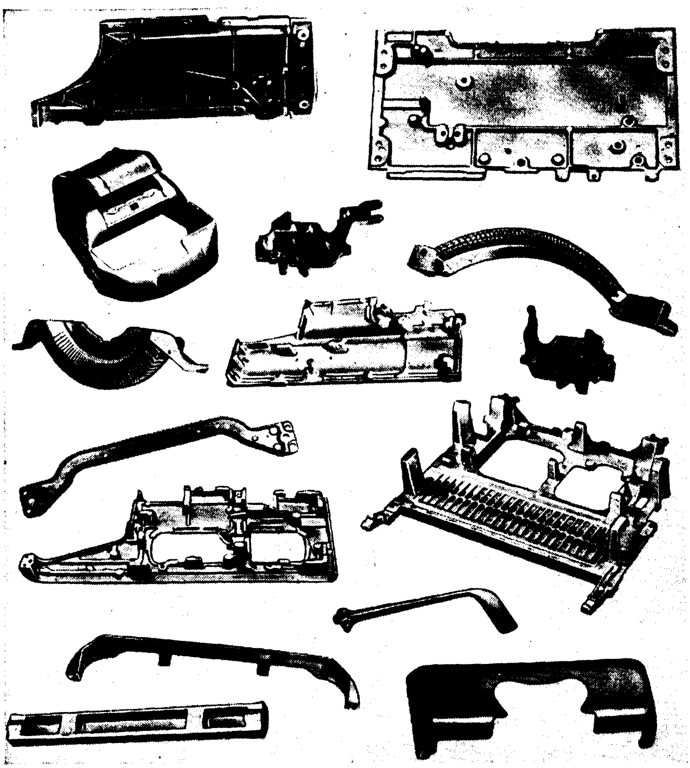


FIG. 7.22. Aluminum die castings for typewriters and other business-machine equipment.

phones, postage meters, and pencil sharpeners (Fig. 7.22). Other end uses of aluminum die castings are in airplane parts and appliances, railroad equipment, textile machinery, outboard motors, and gasoline-pump and service-station equipment, to mention but a few.

MAGNESIUM DIE-CASTING ALLOYS

Die casting of magnesium has greatly increased within the past few years, primarily because of the extreme lightness of the finished parts. The relative weights of various structural metals are shown in Table 7.11.

On an equal volume basis, magnesium is less than one-fourth the weight of steel and two-thirds the weight of aluminum—and light weight is important for

1. Saving power and increasing the efficiency of machines that have moving parts.
2. Decreasing operator fatigue due to manual handling of equipment.
3. Increasing payload in the field of transportation.

Magnesium possesses other important characteristics besides ultra lightness. It possesses a relatively high thermal conductivity and has good energy absorption qualities; it can be machined at higher speeds and with greater economy than can any of the other die-casting alloys; and, despite its low modulus of elasticity, it can be used to obtain greater rigidity with no increase in weight over structures made of aluminum or steel.

Moreover, despite the general impression to the contrary, magnesium and magnesium alloys have relatively good corrosion resistance in outdoor atmospheres. Parts of bare magnesium have been exposed to various outdoor exposures for as long as 15 years, the only effect being the formation of a gray, adherent oxide film.

Magnesium-base alloys have lightness of weight as their chief characteristic, although they also possess high strength-weight ratio and ease of machinability, are nonsparking and nonmagnetic, and maintain good stability under most conditions.

TABLE 7.11. RELATIVE WEIGHTS OF METALS

Metal	Specific gravity	Relative weight	Lb/cu in.	Lb/cu ft
Magnesium alloys	1.8	1.0	0.065	112
Aluminum alloys	2.8	1.6	0.101	175
Zinc	7.1	3.9	0.256	443
Cast iron	7.2	4.0	0.260	450
Tin	7.3	4.1	0.264	456
Steel	7.9	4.4	0.285	493
Brass	8.5	4.7	0.307	531
Bronze	8.8	4.9	0.318	550
Nickel	8.9	4.9	0.322	556
Copper	8.9	4.9	0.323	559
Lead	11.3	6.3	0.408	706

Metallurgy of Magnesium-base Alloys. Although there are a number of magnesium alloys which can readily be die-cast, the standard magnesium-base die-casting alloys most widely used at the present are those covered by ASTM B94-49T, the chemical compositions of which are given in Table 7.12.

TABLE 7.12. CHEMICAL COMPOSITION OF MAGNESIUM-BASE DIE-CASTING ALLOYS *

Metal	Composition, per cent		
	Alloy AS100	Alloy AZ91A	Alloy AZ91B
Aluminum	9.0 to 11.0	8.3 to 9.7	8.3 to 9.7
Manganese	0.10 min	0.13 min	0.13 min
Zinc	0.30 max	0.4 to 1.0	0.4 to 1.0
Silicon	1.00 max	0.5 max	0.5 max
Copper	0.05 max	0.10 max	0.3 max
Nickel	0.03 max	0.03 max	0.002 max
Magnesium	Remainder	Remainder	Remainder

* As given in ASTM B94–49T.

The most commonly used alloy of the three is the AZ91, which has almost wholly displaced the AS100 alloy. AZ91A and AZ91B are practically of the same composition and may be used interchangeably, the AZ91A merely being of higher purity. For most applications it is not necessary to resort to the use of the AZ91A alloy.

The AZ91 alloy combines good casting characteristics with adequate mechanical properties and corrosion resistance. In addition, to be covered by ASTM B94-49T, this alloy also conforms to the following specifications:

Dowmetal *R*
SAE 501
AMS 4490
U.S. Army Air Forces AN-M-16
Naval Aeronautical AN-M-16
Navy Dept. 46 M 11

The typical mechanical properties of die-cast magnesium alloys, obtained on standard ASTM test bars, are given in Table 7.13.

TABLE 7.13. MECHANICAL PROPERTIES OF MAGNESIUM-BASE DIE-CASTING ALLOYS *

Property	Alloy AS100	Alloys AZ91A and AZ91B
Tensile strength, psi	29,000 to 34,000	29,000 to 34,000
Yield strength, psi	20,000 to 22,000	21,000 to 23,000
Elongation in 2 in., per cent	1 to 3	2 to 5
Brinell hardness	62	60
Charpy impact strength, ft-lb	0.5 to 2.0	1 to 3

* As given in ASTM B94–44T.

Other properties of the AZ91 alloy in the die-cast state are:

Thermal conductivity, cgs units	0.17
Electrical conductivity, microhm-cm	0.059
Electrical resistivity, microhm-cm	17.0
Coefficient of thermal expansion (70°F to 212°F)	0.0000145 per °F
Specific heat, cal/g/deg C	0.249
Modulus of elasticity, psi	6,500,000
Modulus of rigidity, psi	2,400,000
Poisson's ratio	0.35

The effect of high temperatures on the mechanical properties is shown in Fig. 7.23.

Effect of Alloying Constituents of Magnesium-base Alloys. As is the case with most other elements, magnesium is seldom, if ever, cast in the elementary state, chiefly because of the relatively poor properties and the poor casting characteristics of the pure metal. Therefore it is essential that magnesium be alloyed with other metals to produce the most desirable properties. Aluminum, zinc, and manganese are the most commonly used alloying metals, while other metals such as cerium, zirconium, beryllium, and calcium have been used.

Aluminum is the most important and has the most significant effect of any of the alloying metals. In amounts of up to 10 per cent, aluminum increases the strength and hardness of magnesium alloys. Aluminum combines with magnesium to form a phase described variously as Mg_3Al_2, Mg_4Al_3 or as β(MgAl) which forms a eutectic with magnesium. Magnesium can hold 12.7 per cent aluminum in solid solution at the eutectic temperature. The eutectic shows up as white particles of Mg_4Al_3 in a solid-solution matrix. The Mg_4Al_3 particles usually occur along the grain boundaries, although they may also occur occasionally in the grains.

Zinc. Zinc is effective as an alloying constituent in magnesium and is invariably used in connection with aluminum to improve the mechanical properties. In addition to improving properties, zinc aids in

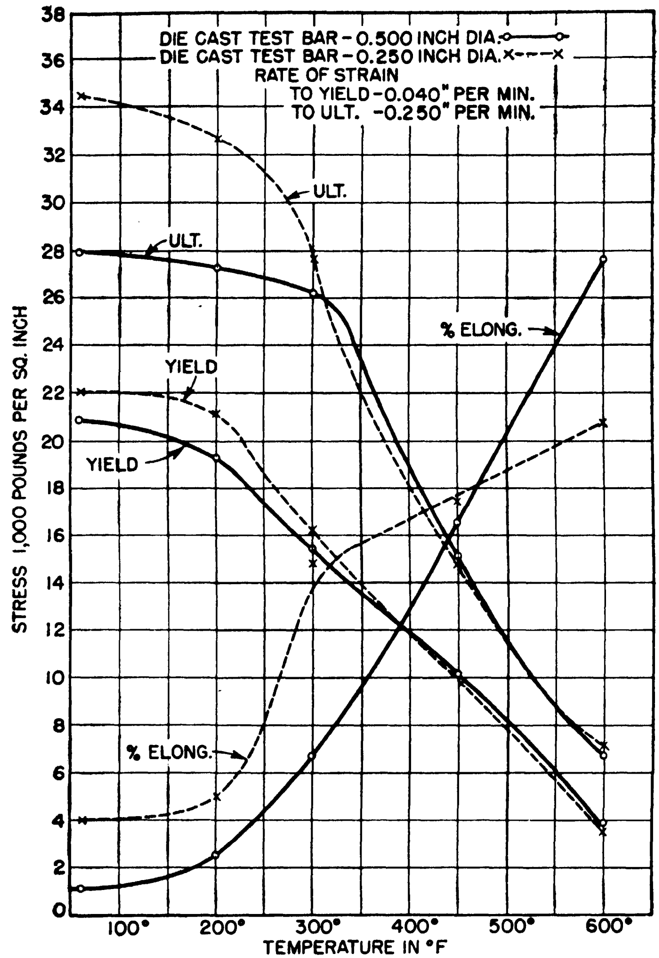


FIG. 7.23. How high temperatures affect the mechanical properties of die-cast magnesium AZ90 alloy.

castability and aids in overcoming or minimizing the harmful corrosion effects of certain other metals, notably iron and nickel. In amounts greater than 1.0 per cent, however, zinc causes hot-shortness and cracking in die casting, although for sand casting and other slower cooled casting methods, the zinc content may be as high as 3 per cent.

Zinc does not occur as a binary phase but is found dissolved in the magnesium or the magnesium-aluminum phase in ternary alloys.

Manganese. The main function of manganese in magnesium alloys is to improve corrosion resistance, especially in salt atmospheres. The amount of manganese that can be held in magnesium is limited by its solubility. In the absence of aluminum, magnesium can hold up to 1.50 per cent manganese. In aluminum-magnesium alloys, the solubility of manganese is reduced to about 0.25 per cent.

Manganese in binary alloys occurs in solid solution or as hard gray particles of elementary manganese.

Beryllium. Beryllium in very small amounts is added to magnesium alloys to minimize burning and retard oxidation of molten magnesium alloys. The amount of beryllium is seldom over 0.001 per cent. Beryllium is only very slightly soluble in magnesium.

Calcium. Like beryllium, the main function of calcium is to reduce oxidation of magnesium alloys in the molten state. When present in amounts greater than 0.10 per cent, calcium occurs as Mg_2Ca. When present in this amount, however, calcium combines directly with any silicon present to change the appearance of the magnesium silicide (Mg_2Si) constituent. In magnesium-aluminum alloys, calcium may form an irregular gray-appearing constituent closely associated with the magnesium-aluminum phase.

Silicon. Silicon is considered as an impurity in magnesium alloys, although it has been purposely added to some alloys in amounts up to 0.5 per cent to increase the fluidity of the alloy during casting. Silicon decreases corrosion resistance of magnesium alloys, especially if iron is also present.

Silicon is only slightly soluble in magnesium and generally shows up as Mg_2Si phase, which can readily be detected by its distinctive blue color under the microscope. When present in large amounts (approximately 0.50 per cent) it may show up as a type of Chinese script structure.

Tin. Tin has been found of some limited use when alloyed with magnesium with small amounts of aluminum; it serves to increase ductility. Tin is only slightly soluble in magnesium. Above the maximum solubility, tin may form Mg_2Sn, which appears as a gray constituent, subject to change of color by etching.

Zirconium. Zirconium has a grain-refining effect which has been found beneficial in wrought forms of magnesium, but as yet it is not of too great an advantage in casting alloys.

Iron, Nickel, and Copper. These elements are considered as harmful impurities in magnesium alloys and therefore must be held down to

established limits below which they are not harmful. In commercial grades of magnesium alloys, both iron and nickel may be present to the extent of 0.01 to 0.03 per cent, but for the maximum corrosion resistance 0.005 per cent nickel is the upper limit. Copper may affect corrosion resistance when present beyond 0.10 per cent.

The grain structure of one of the standard magnesium alloys containing these elements is shown in Fig. 7.24.

Melting Procedures for Magnesium-base Alloys. The sulfur-dome melting method is used almost universally in this country for melting magnesium die-casting alloys (Fig. 7.25). It is different from other possible magnesium-melting practices in that it uses No. 220 flux, which has the characteristic of being able to refine the metal but does not have the property of giving surface protection.

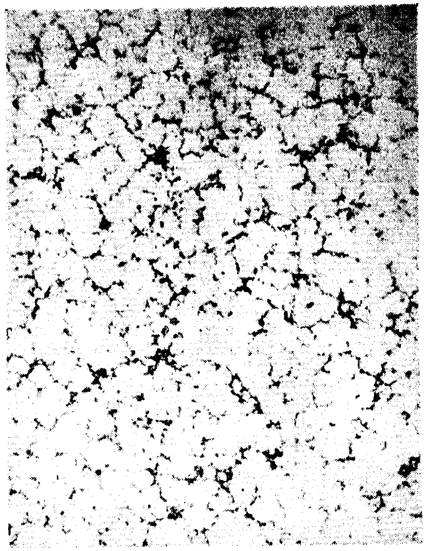


FIG. 7.24. Typical photomicrograph of pressure die-cast magnesium AZ90 alloy, 500×, etched 2 sec in 0.5 per cent hydrofluoric acid.

Since the die-casting process requires the introduction of a ladle into the pot many times per hour, the use of a flux that gives surface protection might lead to the inclusion of flux in the metal because of continued agitation. For this reason, No. 220 flux has been definitely designed to do the refining and then settle to the bottom, so that it may be completely removed from the pot with the sludge. Surface protection in this pot is provided by an atmosphere of sulfur dioxide which usually is generated by burning sulfur in the hollow dome that acts as a cover for the melting pot.

The ladle is introduced into the pot through a small opening in the cover. The sulfur dioxide generated in the hollow dome is allowed to enter the space just above the metal in order to blanket the surface and inoculate the air entering through the ladle opening. The primary meltdown is done by dusting the surface of the pot with the No. 220 flux (Table 7.14) and charging the solid metal into the pot, with careful attention to fluxing to prevent oxidation. When the batch is molten, it is stirred thoroughly with the flux to agglomerate the oxide. It is then allowed to stand for about 10 min until the sludge and flux settle, after which it is ready for sludging.

Sludging consists of removing the sludge with a skimmer that is perforated with ¼-in. holes. The skimmer is preheated, put into the metal, and used to scrape the bottom and sides of the pot. When the skimmer is brought up with the metal and sludge, the molten metal runs through the perforations, leaving only the sludge, which is dumped into a pre-

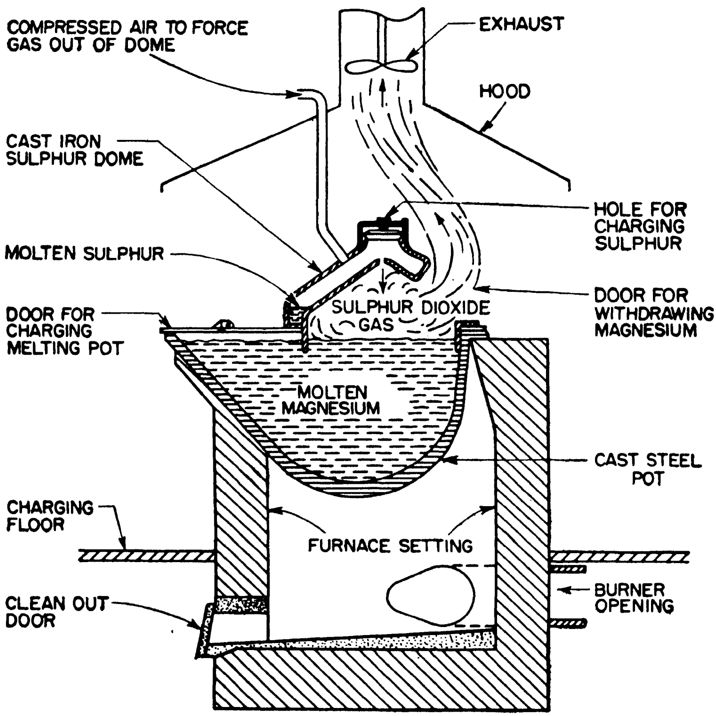


FIG. 7.25. Pot setting and metal-protection system of sulfur-dome furnaces for melting magnesium alloys.

heated pan. After the sludge is removed, any dross or unsettled flux is skimmed from the surface of the metal. At this stage, it is advisable to allow the melt to stand about 10 min before it is dipped from the pot.

The foregoing procedure is followed in starting up a new pot, but in normal operation it is preferable practice to keep the die-casting pot relatively full of metal. This may be accomplished by adding fresh ingot at a rate sufficient to maintain a constant metal level, or, still better, to do all the melting in a separate melting unit known as a *premelter* and then transfer the molten, refined metal directly to the casting pot by tilting or ladling. If scrapped castings, butts, gates, etc., are charged

into the premelter along with ingot, it is preferable to use No. 310 flux for the premelting operation.

TABLE 7.14. COMPOSITION OF FLUXES USED FOR MAGNESIUM-ALLOY DIE CASTING *

Flux No.	Composition, per cent	Remarks
220	57.0 potassium chloride 28.0 calcium chloride 12.5 barium chloride 2.5 calcium fluoride	A heavy flux used for refining metal in a covered pot provided with sulfur dioxide surface protection.
230	55.0 potassium chloride 34.0 magnesium chloride 9.0 barium chloride 2.0 calcium fluoride	Highly fluid flux used for surface protection allowing parting for ladling operations. Good refining qualities.
310	20.0 potassium chloride 50.0 magnesium chloride 15.0 calcium fluoride 15.0 magnesium oxide	Flux is fluid at the start of melting and refining, drying out to crust that can be readily removed or moved back for direct pouring.
320	76.0 manganese chloride 13.0 calcium fluoride 11.0 magnesium oxide	This flux is used primarily for introducing manganese into the alloy. Flux contains about 33 per cent manganese by weight.
180	78.0 sulfur 19.5 boric acid 2.5 ammonium borofluoride	Ladle and crucible protector agent.
190	7.5 sulfur 12.5 boric acid 80.0 ammonium silicofluoride	Ladling and skimming agent.

* Courtesy Dow Chemical Company.

The melting and refining of die-casting scrap present a special problem different from that for the bulk of magnesium scrap in that a certain proportion of carbonaceous materials such as lubricants are present on the scrap; hence, melting and refining in No. 230 flux, as in ordinary practice, is not satisfactory. A reddish scum, or film, of the carbonaceous material seems to stay suspended throughout the metal. This behavior is avoided by melting such scrap in open pots or crucibles, using No. 310 flux.

The No. 310 flux has the characteristics necessary to agglomerate and

refine the carbonaceous film. Melting procedures are similar to the open-pot operation for scrap recovery.

The usual pouring-temperature range for die casting is from 1175 to 1250°F, so the oxidation tendency for the metal is relatively low. Because of the protective atmosphere in the pot, the metal acquires a thin surface film which must be parted when the ladle is introduced. It is always desirable to maintain a clean metal surface, since this material is sometimes pyrophoric and may lead to a popping or flashing. If there is evidence of undue oxidation on the metal surface after ladling, it means that the sulfur dome is not working properly. Sometimes a slight dusting of sulfur or a similar agent on the edge of the dome may be required to control oxidation. In no case would fresh flux be added to the pot unless the entire refining and sludge removal processes were to be repeated. In continuous operation, particularly if ingot is added directly to the pot, it may be necessary to reflux the pot every 4 to 8 hr. Ordinarily, from 1 to 3 per cent of No. 220 flux is used. Unless absolutely unavoidable, it is not good practice to make alloy additions in the premelting or die-casting pot.

Control of the alloy usually is maintained by the following procedure:

1. Using certified alloy ingot.
2. "Blending in" premelted and refined die-casting scrap of known composition, which is periodically analyzed in the premelting furnace or in the actual die-casting pot.
3. Certification of the cast product on the basis of analyses of randomly selected castings from a given lot of actual castings.

Die-casting Procedure for Magnesium-base Alloys. Die temperatures for magnesium ordinarily run from 250 to 600°F, with 400°F being a good average. Heat is applied to the die by electric strip heaters or a gas torch. The heat supplied to the dies should be as uniformly distributed as possible to prevent warpage. In continuous operation, heat from the metal keeps the die at operating temperature, and supplementary heat need be applied only after interruptions. Sometimes water-cooling channels in the die are needed to limit the temperature to the desired degree. Although the operating temperature for any individual die can be found only by actual operation, large castings generally require water cooling of the die. Freedom from surface swirls and cold shuts is possible only when dies are maintained at the proper temperatures. The dies gradually become coated with a thin film of oxide, and too high a die temperature may cause an excessive oxide film and hence rough surfaces on the castings.

When the metal and dies have been made ready for casting, the pouring ladle is preheated on the rim of the pot before being introduced into the molten metal. After this preheat, the ladle is held under the surface of the molten metal in the pot to bring it up to the metal temperature; this prevents the metal from freezing to the ladle in the dipping operations. The ladle is filled by parting the protective film with the back of the ladle and dipping the ladle into the bath. The ladle is then lifted from the pot and transported to the machine, and the contents poured into the well, the injection being applied or the shot being made as soon as the last bit of metal from the ladle has been poured.

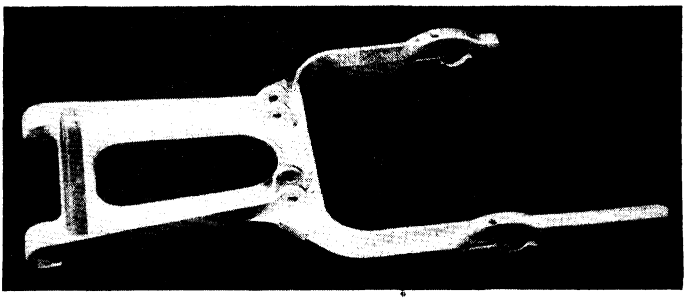


FIG. 7.26. Take-up bobbin for textile machine die-cast of magnesium. Such castings are being increasingly applied to machines in which low inertia of moving components is important. In magnesium, this part weighs 0.670 lb; in aluminum, 0.974 lb.

Accurate timing of this operation and the shot speed is essential to the production of good-quality castings. Only experience on a given job will tell how soon the die should be opened after the shot. If, on repeated ladling, spots of burning occur on the surface of the molten bath, they may be extinguished by a sprinkle of protecting agent No. 181 or No. 190.

The usual pouring-temperature range for the metal is 1175 to 1250°F, depending upon the design of the casting being made. When it is necessary to go above 1300°F to obtain a good casting, the remedy should be sought in improved gating. In no instance should a pouring temperature of 1300°F be exceeded, since the sulfur dioxide in the dome will not provide sufficient protection for the metal at this temperature. The lowest casting temperature that will result in sound castings should always be sought.

Applications of Magnesium Die Castings. Besides the applications previously mentioned for magnesium die castings, namely, portable typewriters, stenotype and business machines, cases and housings, portable tools, and parts for textile, conveying, and packaging machinery (Fig.

7.26), magnesium die castings also are used in aircraft for parts in the automatic pilot, starting motors, and gyro instruments, and for other miscellaneous components.

The use of magnesium in the automotive field in this country has been limited, doubtlessly due to the competition of other base die-casting alloys. In Europe, however, a considerable and far greater use is made of this alloy in automotive design. In the future more use of magnesium die castings may be made here, especially if the price changes sufficiently to make it attractive for some parts where its particular properties can be utilized. Indications point to the possible use of magnesium die castings for automotive wheels.

Magnesium die-cast wheels have been standard equipment on aircraft for a number of years, yet there has been no experience with magnesium automobile wheels. The advantages that magnesium automobile wheels will have over the present steel wheel are said to be

1. Remarkably reduced tire wear.
2. Improved steering control, especially on uneven roads.
3. Reduced vibration in wheel suspension.
4. Reduced unsprung weight (improved ridability).
5. Lighter weight (facilitating tire changing).

COPPER-BASE ALLOYS

Copper-base die castings—almost always brass—are used for a variety of small and medium-sized parts that are subjected to wear in service. Although the corrosion resistance of brass die castings is excellent, they usually are not applied for decorative purposes because the protective oxide film that forms on the surface detracts from its appearance, and because plated or colored zinc or aluminum die castings usually are less costly. However, brass die-casting alloys have excellent characteristics and high strength, so that they are ideal for many structural parts.

Metallurgy of Brass Die-casting Alloys. The three brass alloy compositions most frequently used for die castings are designated as alloys A, B, and C. The chemical compositions of these alloys are listed in Table 7.15; and the mechanical properties, in Table 7.16. Die castings can be produced in other copper-base alloys, but present practice dictates the use of only those alloys that have melting points under 1650°F. Aluminum bronzes, tin bronzes, and other high-copper-content alloys can be readily die-cast, but the melting points and casting temperatures of these alloys are too high to be practical or economical with the die materials at present available.

TABLE 7.15. CHEMICAL COMPOSITION OF STANDARD COPPER-BASE (BRASS) DIE-CASTING ALLOYS *

Metal	Composition, per cent		
	Alloy type A	Alloy type B	Alloy type C
Copper	57.0 min	63.0 to 67.0	80.0 to 83.0
Silicon	0.25 max	0.75 to 1.25	3.75 to 4.25
Lead	1.50 max	0.25 max	0.15 max
Tin	1.50 max	0.25 max	0.25 max
Manganese	0.25 max	0.15 max	0.15 max
Aluminum	0.25 max	0.15 max	0.15 max
Iron	0.25 max	0.15 max	0.15 max
Magnesium	....	0.01 max	0.01 max
Other elements	0.50 max	0.50 max	0.25 max
Zinc	30.0 min	Remainder	Remainder

* As given in ASTM B176-49T.

TABLE 7.16. MECHANICAL PROPERTIES OF STANDARD BRASS DIE-CASTING ALLOYS *

Property	Alloy type A	Alloy type B	Alloy type C
Ultimate tensile strength, psi	45,000	58,000	90,000
Yield strength (0.2 per cent set), psi	25,000	35,000	30,000
Elongation in 2 in., per cent	10	15	25
Charpy impact strength, ft-lb	30	40	40
Brinell hardness	120	130	170

* As given in ASTM B176-49T.

Alloy A is a general-purpose low-cost brass composition that has wide limits as to impurities. Alloy B is a higher purity alloy having good castability and good mechanical properties in the die-cast state. Alloy C is harder and has better physical properties than alloy B and consequently finds considerable use where resistance to wear is an important requirement. The effect of elevated temperatures on these alloys is shown in Tables 7.17 and 7.18.

Die castings of this alloy have been known to outwear other hard materials, and in a number of cases it has replaced steel parts.

Note that in the latter two alloys, the lead content is very low (0.15-

TABLE 7.17. EFFECT OF TEMPERATURE ON MECHANICAL PROPERTIES OF BRASS ALLOYS
(Short-time elevated temperature test *)

Alloy	Testing temperature	Mechanical properties		
		Yield strength (0.2 per cent set), psi	Ultimate tensile strength, psi	Elongation in 2 in., per cent
B	Room	36,725	75,000	30
	Room	38,425	73,500	21
	200°F	......	73,478	31
	200°F	41,625	73,274	27
	300°F	41,625	71,130	34
	300°F	42,225	71,028	34
	400°F	41,625	65,622	44
	400°F	38,575	64,100	42
	500°F	34,150	53,706	57
	500°F	29,690	52,482	23 †
C	Room	48,250	86,600	20
	Room	48,975	85,500	18
	200°F	49,275	89,800	27
	200°F	48,490	87,600	23
	300°F	51,750	90,100	28
	300°F	49,000	87,000	22
	400°F	50,450	86,100	26
	400°F	......	83,900	19
	500°F	45,600	73,478	12
	500°F	42,850	71,844	11

* Standard test bars, ½ hr at specified temperature.
† Broke outside gage marks.

0.25 per cent maximum). This is because that lead, in any but the smallest amounts, tends to segregate and liquate from the base metal, thus causing ugly gray spots of metallic lead to form on the casting surfaces. Lead also contributes to hot-shortness of the alloy in casting, contributes to the oxide coating of the die, and is distributed as globules in the grain boundaries of the alloy, thus forming planes of weakness. Its only advantage is that it improves machinability. The grain structure of some of the standard brass alloys can be seen in the photomicrographs, Fig. 7.27.

The effect of other elements on the characteristics of brass die-casting alloys is as follows:

Tin. Tin increases hardness, but over 1 per cent in the alloy for brass die casting results in difficulty in machining. It does, however, aid corrosion resistance and improve surface finish.

Bismuth. Bismuth is particularly harmful to mechanical properties because of its distribution in the grain boundaries, thus causing brittleness. Its content preferably should be kept below 0.005 per cent.

TABLE 7.18. EFFECT OF TEMPERATURE ON MECHANICAL PROPERTIES OF BRASS ALLOY
(Long-time elevated temperature test)

Alloy	Testing temperature	Mechanical properties		
		Yield strength (0.2 per cent set), psi	Ultimate tensile strength, psi	Elongation in 2 in., per cent
C	Room	49,750	90,300	23
	400°F *	48,350	78,754	15
	Room	52,100	86,450	24
	400°F †	53,350	78,350	15

* Aging time, 125 hr at 400°F.
† Aging time, 300 hr at 400°F.

Antimony. Antimony acts similarly to bismuth, and hence it also should be held below 0.005 per cent.

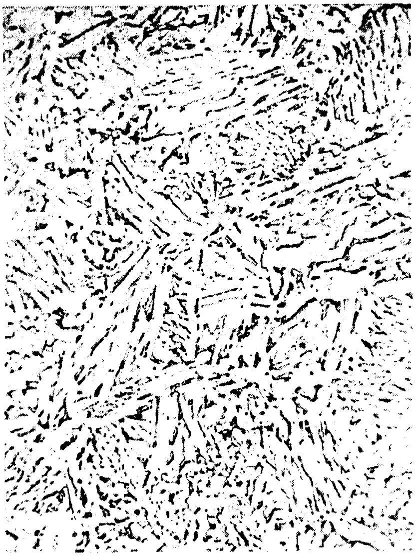
Arsenic. In brass alloys, arsenic is deleterious; as little as 0.05 per cent greatly reduces ductility.

Sulfur, Tellurium, and Selenium. These have a harmful effect on the mechanical properties of brass die castings and should be kept at a minimum or eliminated altogether. The presence of copper sulfide, telluride, or selenide greatly reduces ductility.

Iron. Iron preferably should be kept below 0.25 per cent since it has a pronounced hardening tendency and reduces corrosion resistance.

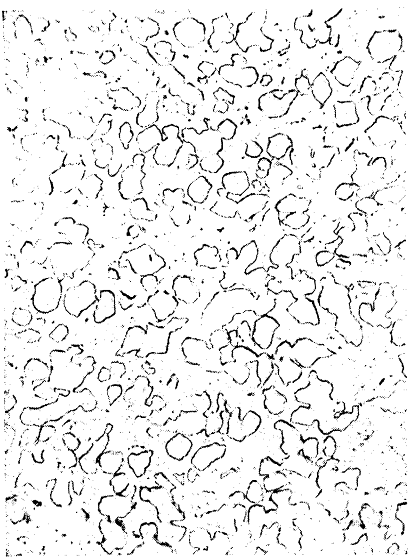
Manganese. In brass alloys, manganese increases hardness and tensile properties and decreases elongation. The alloy known as *manganese bronze,* essentially a brass alloy containing small amounts of manganese, can be die-cast with satisfactory results.

Magnesium. Magnesium is a strong deoxidizer, and small amounts of it aid in removing oxygen and impurities. If and when it is used, however, it should be only in amounts sufficient to react with the oxides, without leaving any residual magnesium in the alloy.



Alloy A

Alloy B



Alloy C

FIG. 7.27. Photomicrographs of three ASTM brass alloys pressure die-cast. All three were taken at 500× and etched in following solution: 5 g ferric chloride, 2 ml hydrochloric acid, and 96 ml ethyl alcohol.

Aluminum. Aluminum is beneficial for deoxidizing, retarding oxidation, and preventing the volatilization of zinc at elevated temperatures. Its content should best be held below 0.25 per cent.

Nickel. Nickel has the effect of improving mechanical properties and corrosion resistance.

Silicon. Silicon is extremely beneficial in brass die-casting alloys. Its effect is to lower the melting point, increase fluidity, increase mechanical

FIG. 7.28. Pouring a brass melt into a bull ladle for transfer to the casting department.

properties, and deoxidize and tend to counteract or diminish the deposition of oxides on the die surfaces. Silicon has quite a quiescent effect on brass die-casting alloys, which must be held in the molten state for long periods of time, and thus prevents excessive oxidation and loss of zinc.

Melting Procedures for Copper, Brass, and Bronze. Like other alloys, brass is melted in a separate melting room and is then transferred to the casting machine by means of bull ladles, cars, or similar means (Fig. 7.28).

In the melting of copper, brasses, and bronzes, any of the following types of melting furnace may be employed:

1. Gas-, oil-, coal-, or coke-fired crucible pit furnaces.
2. Gas- or oil-fired crucible tilting furnaces.
3. Gas- or oil-fired direct-flame furnaces.
4. Electric-induction furnaces.
5. Electric-arc furnaces.
6. Cupolas.
7. Reverberatory furnaces, gas- or oil-fired.

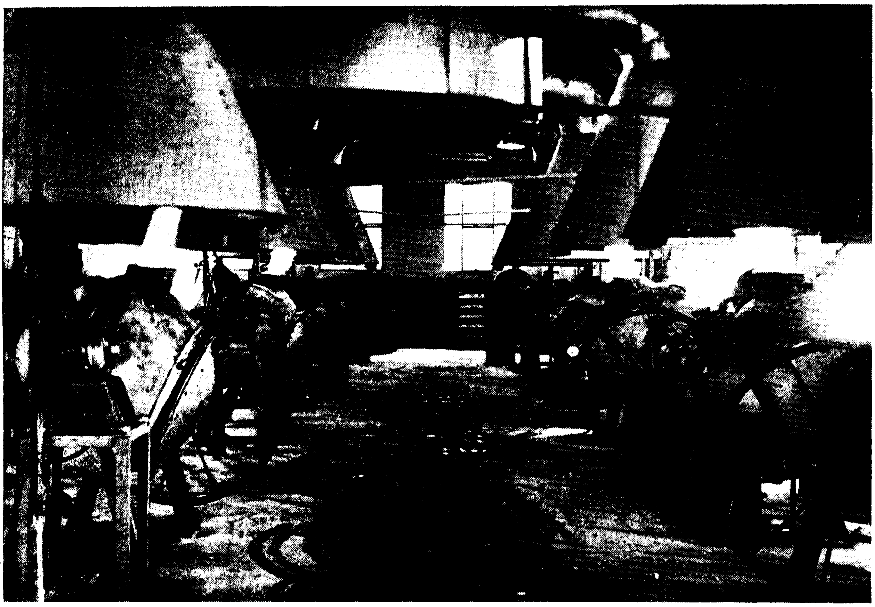


Fig. 7.29. Brass foundry containing a battery of direct-flame furnaces.

Of these various types, the direct-flame furnaces and electric furnaces are the ones most adaptable for brass die casting, and only these types will be briefly discussed.

Direct-flame Furnaces. This type of furnace is one in which the flame impinges directly on the metal charge which is contained in a barrel-like or similarly shaped device held on trunnions and capable of being rotated for pouring. Either gas or oil may be used for fuel. Such furnaces are suitable for brass die casting since they offer flexibility in the melting of relatively small charges and can readily be used for the melting of successive charges of alloys of different compositions.

Melting is quite rapid and at low cost, although the losses of metal through oxidation and volatilization are higher than those usually found

in electric melting furnaces. Since, in this type of furnace, the flame and combustion gases are in intimate contact with the metal during melting, it is important to maintain an oxidizing atmosphere to minimize the harmful effects of gases (hydrogen or hydrocarbon gases) arising from the fuel. It is well to maintain an oxygen content of up to 0.5 per cent in the combustion gases. Above this maximum, greater loss of metal through oxidation may occur. The oxygen content may be periodically

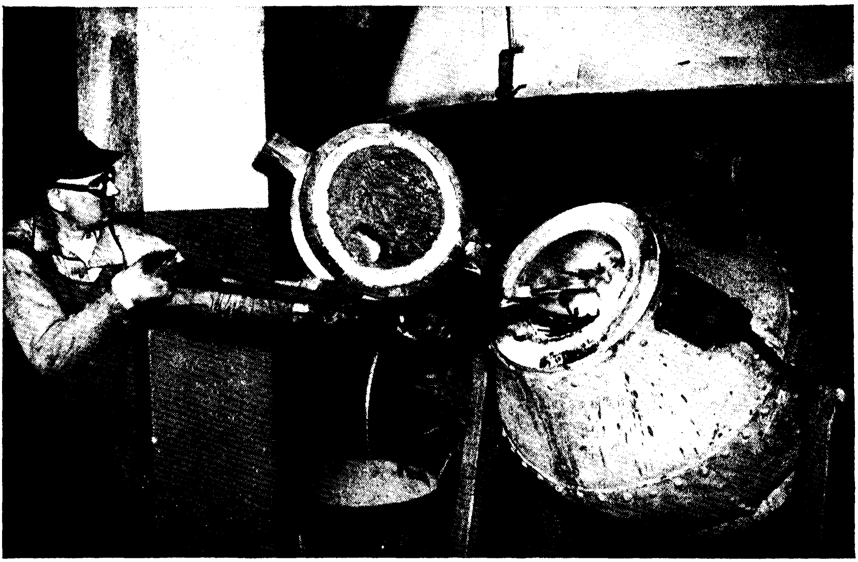


FIG. 7.30. Charging a direct-flame brass furnace with scrap.

checked by gas analysis, although in practice the skilled melter may be able to judge the atmosphere adequately by the color and size of the flame issuing from the furnace.

Figures 7.29 and 7.30 show this type of furnace during melting and charging operations.

Electric Furnaces. The use of electric melting furnaces for copper-base alloys has greatly increased during the past couple of decades. Most of the large brass fabricating mills, especially those of wrought-metal products, use some electric furnaces exclusively.

The cost of electric-furnace installation is usually high, chiefly because of the need for special transformer and other accessory equipment. Because of these high costs, electric furnaces can be economically operated only where the melting rate is relatively high, so that the cost per pound of metal burden can be kept low. Continuous operation of electric fur-

naces is necessary to maintain high thermal efficiency. The advantages of electric melting, however, are such as to overcome the disadvantages of these high costs in many cases. The outstanding advantages of electric melting may be listed as (1) comparatively low metal losses; (2) high quality of metal, mainly through lack of gas absorption; (3) better uniformity of alloy composition through lower losses of volatile elements; and (4) improved working conditions, especially concerning ambient temperatures of operation.

Of the electric furnaces, the low-frequency-induction furnace has been used to the greatest extent in the melting of brass alloys.

The low-frequency furnace has certain characteristics which force its ready adaptation for brass alloys, supplanting other methods. The furnaces operate by the induction of low-frequency current in a closed circuit of liquid metal built around a primary core of a transformer. The liquid coil of metal is made so that the upper part of the coil is the bottom of the melting chamber. The furnace consists of a cylindrical chamber with ducts extending from the bottom of the chamber around the primary. The operation of the furnace is started by pouring sufficient liquid metal, melted from an outside source, to fill the bottom of the furnace, so that a closed liquid circuit is formed before the electric current is turned on. This metal must be kept molten throughout the operation of the furnace, and therefore sufficient current must be kept flowing to maintain the molten heel of metal, even during stand-by times.

One of the chief characteristics of this type of furnace is that the molten alloy is kept constantly and automatically stirred, which ensures uniformity of heating and thorough mixing of the ingredients of the alloy. This stirring action is due to electrical phenomena associated with a heavy current density in the duct. It causes discharge of metal from the ducts, which greatly assists in the melting and stirring of the liquid metal. After the current is applied to the molten heel of metal at the start, solid metal in the form of scrap or ingot may be added to the furnace chamber and melted through the heating of the metal in the duct.

Rocking Arc Furnace. In this type of furnace the metal is melted by radiation from an electric arc between carbon or graphite electrodes. The furnace is constructed so that it is capable of being oscillated back and forth while the metal is being melted, the action of which promotes uniformity in mixing and alloying. This furnace can be used for general jobbing work and is adaptable for most nonferrous alloys. It is possible to run various alloys one after another, especially if any minor contamination by metals remaining adhered to the refractory lining can

be tolerated. The furnace is capable of being completely emptied and cleaned. Melting is quite rapid, but in operation care must be exercised to prevent contamination of the melt from both the siliceous refractory and the carbon electrodes.

Brass Melting Losses. In the melting of brass alloys, particularly the high-zinc-content alloys, the control of the loss of zinc through volatilization is an important problem, and means must be taken to minimize this loss. In addition to the loss of zinc, losses of metal occur by oxidation and dross and skimmings formation; the latter is a mixture of dross and particles of occluded metallics that is removed from the melt before pouring or periodically from the surfaces of the casting-machine pots. The metallics of the latter can largely be reclaimed and remelted, but the losses of zinc by volatilization are not generally recoverable.

The loss of zinc is much less in electric furnaces, especially the induction types, than in open-flame furnaces. Whereas as high as a 3 per cent loss of zinc may be found in open-flame furnace melting, electric-induction furnaces may show a loss of only between 0.10 and 0.60 per cent. Loss through oxidation of brass alloys in electric furnaces is also lower than in open-flame furnaces. Any loss of zinc in melting naturally causes changes in alloy composition. To make up such loss it is necessary to add the required amount of pure zinc to the charge prior to pouring. This is especially necessary where specifications of alloy composition are strictly imposed.

The type of metal being melted may have a strong bearing on metal losses. The nature and amount of scrap used in a charge might materially affect the yield of a melt. Lightweight, thin sheaf, and finely divided scrap such as turnings and sweepings have a strong tendency to oxidize readily during the melting operation before coming into contact with the molten alloy. It is good practice to have such lightweight scrap briquetted into bundles of 20 to 25 lb, which will make for more easy handling and will readily go beneath the surface of the molten alloy.

Turnings resulting from machining operations are always difficult to handle and remelt. Turnings should be dry and substantially freed from moisture and oil before being added to the furnace. Thoroughly dried turnings quickly submerged in a molten bath of brass, with the aid of a mechanical pusher, will result in minimizing loss and produce good yield.

Fluxes. When proper control in melting is exercised and especially when the metal charge is clean, there is usually small need for extensive usage of fluxes for brass alloys. However, their use at times is necessary, but when required they should be properly prescribed and used with discriminate care.

In addition to the numerous proprietary fluxes on the market for copper

and brass alloys, most of which are extolled for special purposes, there are some common materials in daily use which may be used singly or in combination with one another, such as charcoal, borax, lime, glass, common salt, fluor spar, carbonates, and sulfates of the alkaline and alkaline-earth metals.

Charcoal is used generally for covering the surfaces of molten brass alloys to form a nonoxidizing atmosphere. Liquid cover fluxes containing borax and/or glass are useful to form protective coatings over a melt and thus prevent oxidation as well as prevent furnace gases from coming into contact with the metal.

The following composition of flux is generally useful for brass alloys: 10 per cent glass sand, 40 per cent borax, and 50 per cent soda ash.

SPECTROGRAPHIC CONTROL OF ALLOY COMPOSITION

The effects of alloying elements on die-casting metals has previously been shown to be significant. It therefore is necessary that the composition of these materials be closely controlled during all phases of production.

Because alloying elements usually are present only in minute quantities, however, it is difficult to use ordinary wet chemical methods for their determination, and quantitative spectrochemical analysis has become the accepted method of checking composition. By spectrographic means, a complete analysis of all constituents can be rapidly and accurately made.

Spectrochemical analysis consists essentially of photographing the spectrum produced from an electrically excited sample, the light from which is dispersed by means of a quartz prism or diffraction-grating spectrograph. Since the intensity and wavelength of the light emitted depends upon the number of atoms of each element present, a quantitative analysis can be made by measuring the intensity of the spectrum lines that are produced.

The spectrographic equipment commonly used is the Bausch and Lomb Littrow quartz-type spectrograph (Fig. 7.31) and the A.R.L. diffraction-grating spectrograph. The accessory equipment necessary for a complete laboratory includes a 2,500- to 5,000-volt a-c arc unit, a high-voltage a-c spark unit, an auxiliary inductance unit, a voltage regulator, a magnetic shutter, a step sector, a densitometer, spectrographic standards, a thermostatically controlled plate-developing machine, a plate washer, a plate drier, a motor-driven carbon sharpener, calculating boards, and other miscellaneous equipment.

The purpose of the spectrograph is to break up the light rays produced

by burning the metal sample in either an a-c arc or a spark gap and to record the resulting spectrum on a photographic plate (Fig. 7.32). The

FIG. 7.31. Quartz spectrograph being used to analyze the chemical composition of metal for die casting. Wet chemical analysis is unsatisfactory.

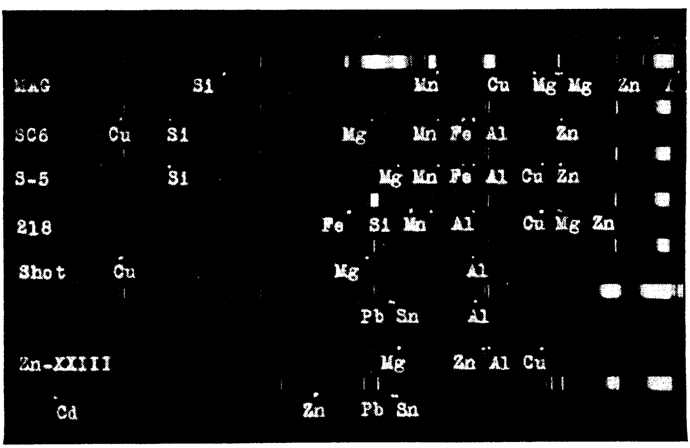


FIG. 7.32. Spectrographic plate, showing the position of the various spectral lines.

auxiliary inductance unit is used to stabilize the a-c spark unit and prevent excitation of air molecules, the lines and bonds from which might otherwise clutter up the spectrum background on the plate. The voltage regulator is necessary to ensure the reproducibility of relative line in-

tensities; the densitometer is required to measure the intensities of the spectrum lines as photographed; and the spectrographic standards provide the basis of comparison with the unknown sample. The purpose of the other accessory equipment is obvious.

Elements of the Spectrograph. The spectrograph consists essentially of the following parts: the slit, the lens system, the dispersing system, and the photographic plate. The slit is formed of two metal jaws which are adjustable so that either one or both move on a line perpendicular to the edge of the jaw.

The lens system consists of a collimator lens and a telescope lens (Fig. 7.33). The function of the collimator lens is to collect the light rays

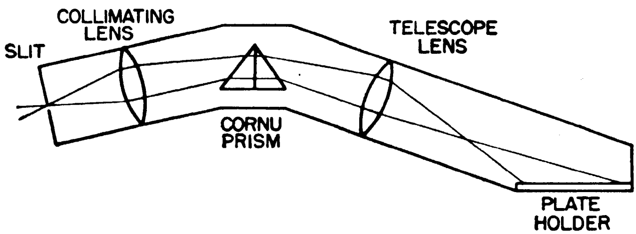


FIG. 7.33. Optical diagram of a medium quartz spectrograph.

coming from the slit and transmit them as a parallel beam on the first face of the prism. The telescope lens collects the rays leaving the last prism face and brings them to a focus on the photographic plate.

The quartz spectrograph employs a quartz prism in its dispersing system. It is composed of two 30-deg prisms, one of right quartz and one of left, in order to prevent the image from doubling. The rotation produced in the first half of the prism is exactly neutralized by the reverse rotation in the second half.

The photographic plate is fitted into a specially designed plate holder which can be raised or lowered so that a number of spectra can be photographed on one plate.

Arc Equipment. The alloy sample can be burned by an a-c arc of from 2,500 to 5,000 volts, by a higher voltage a-c spark, or by a d-c arc. The d-c arc is employed as an excitation source for the detection of small amounts of impurities. However, the d-c arc does not give such constant and reproducible results, in so far as the relative intensities of the spectral lines are concerned, as some other sources. This variation is due in a considerable degree to the wandering of the arc itself. Fluctuations in supply current and voltage produce temperature changes that cause variations in the relative intensities of the lines.

Some of the irregularities of the d-c arc can be avoided by the use of a high-voltage a-c arc source. The a-c arc results in more uniform and reproducible line intensities; it is ideal for analytical problems involving high quantitative accuracy rather than the utmost in sensitivity.

In the higher percentage concentrations—0.1 to 10 per cent—the spark is superior to the arc since it produces large changes in line intensities for relatively small-percentage differences in composition. The primary circuit of the spark unit includes a variable rheostat, a tapped inductance primary on the high-voltage transformer, and a motor-driven timer. The secondary circuit is made up of the transformer secondary, a variable inductance coil, sealed condensers, a relay switch, and a motor-driven spark gap with a manual gap control. A high-inductance unit, housed in a metal cabinet, can be connected to the spark equipment. It contains three inductance coils, each with an inductance of 0.36 mh. A common lead cable connects it to one of the terminal outlets of the spark unit. One of the cables from the spark stand of the spectrograph is plugged into the 0.72-, 1.08-, or 1.44-mh inductance receptacles, thereby adding one, two, or three additional inductance coils in series in the spark circuit. As previously mentioned, a small amount of inductance is desirable since it has been found to prevent the excitation of lines and bands of the air molecules which otherwise cause undesirable confusion and background in the spectrum. To improve the reproducibility of results, a mercury-quartz tubular lamp also can be installed in the spark unit for ultraviolet irradiation of the rotary gap.

For optimum results, a spectrographic laboratory should be maintained at a constant temperature and humidity, since excessive humidity greatly affects the intensity of light emitted from the material being investigated. If the laboratory is not air-conditioned, the interior of the spark unit and the analytical gap of the Petrey stand, on which the sample is burned, must be fed with a supply of dry air. Holes can be drilled in the phase-control arm of the rotary spark-gap assembly, through which small glass tubes can be placed. The air is directed on the gap between the stationary and rotary points. This eliminates, to some extent, the deposition of oxides on the surface of the points and at the same time creates a positive pressure of dry air that does not allow moist air to enter the spark unit from the outside.

Densitometer. The densitometer (Fig. 7.34) is an instrument used to measure the densities of the spectral lines. It is fitted with a holder in which the plate is placed. Light is furnished from a projection lamp mounted below the plate holder. Directly above the plate holder is a slit head on the end of a tube that houses a photoelectric cell. All the light from the projection lamp passes through the clear portion of the

plate. The photocell receives the light and its output is amplified by a bridge-circuit amplifier, thereby actuating a quick-reading galvanometer to the 100 index on the scale.

A motor scanning carriage advances the slit over the spectral line to be read. Some of the light from the projection lamp is absorbed by the line before it reaches the photocell. This lowers the output of the cell and causes a lower reading on the galvanometer scale. A minimum read-

Fig. 7.34. Using densitometers to measure the intensity of the spectral lines from a metallurgical sample.

ing on the galvanometer scale is reached as the slit reaches the center of the spectral line. The reading increases thereafter as the slit passes over the remaining width of the line. The minimum value is recorded, after which a button is pushed to release the slit head from contact with the plate. The operator then may read the next line.

Spectrographic Plates. For spectrographic work an emulsion should have high contrast, so that small variations in composition are shown as variations in line density; small grain size; little tendency to fog, to reduce photometer errors; and uniform sensitivity and contrast over a wide spectral range, to avoid the necessity of more than one calibration curve. Spectrum analysis No. 1 plates made by the Eastman Kodak Company combine most of these properties and are well suited for spectrochemical analysis.

In order to calculate the percentage of each element in an alloy, it is necessary to have a calculating board on which is plotted a gamma curve

of the plate emulsion. This curve gives the relationship between the actual intensity of the spectral radiation and the blackening of the photographic plate.

The gamma curve is plotted in the following manner. Pure iron electrodes are sparked with a 10-sec prespark and a 10-sec exposure, a step sector being used, under the following conditions: power, 2 kva; capacitance, 0.21 μf; inductance, 1.08 mh; slit width, 0.04 mm; slit height, 8.5

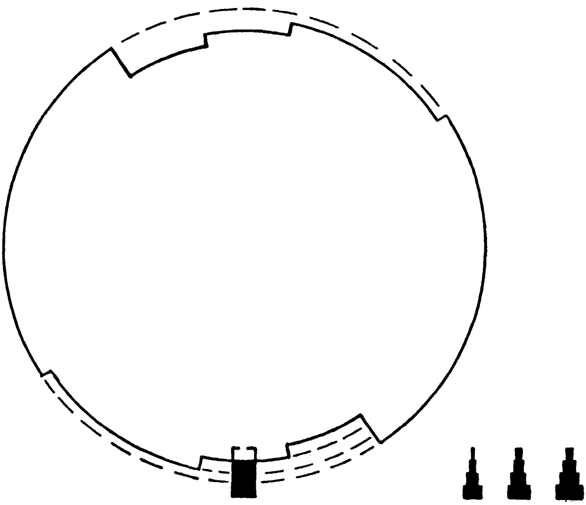


Fig. 7.35. Step sector, which is used to divide the spectral lines into a series of intensity steps.

mm; condensing lens, 15.2 cm. The step sector shown in Fig. 7.35 divides the spectral lines into a series of intensity steps. In this case, four steps are produced. The first step at the top of the line is the lightest. The second step is twice the intensity of the first; the third is twice the intensity of the second; and the fourth step is twice the intensity of the third.

Table 7.19 gives the density readings on the densitometer of the intensity steps of five iron lines. Using these values, the densities of each step can be plotted against the densities of the steps of one-half intensity. Take the values for the second intensity step of line No. 1, which can be called D_1, and the first step of the same line, which can be called D_2. Referring to the curve shown in Fig. 7.36, D_1 is plotted on the ordinate; and D_2, which is one-half of the intensity of D_1, on the abscissa. Thus the first point is established. Next, D_1D_2 is plotted where D_1 is 36.0 and D_2 is 66.5; and finally D_1D_2, where D_1 is 13.2 and D_2 is 36.0. This pro-

TABLE 7.19. DENSITOMETER READINGS OF FIVE TYPICAL IRON LINES

Intensity step	Densitometer readings				
	No. 1	No. 2	No. 3	No. 4	No. 5
1	88.5	70.6	28.0	54.6	76.4
2	66.5	44.0	13.4	28.2	48.0
3	36.0	20.6	6.2	11.6	21.5
4	13.2	7.2	2.4	4.4	7.8

cedure is continued for the four remaining lines in order to fill in the curve (Fig. 7.36). To equate the densities of the spectrum lines with

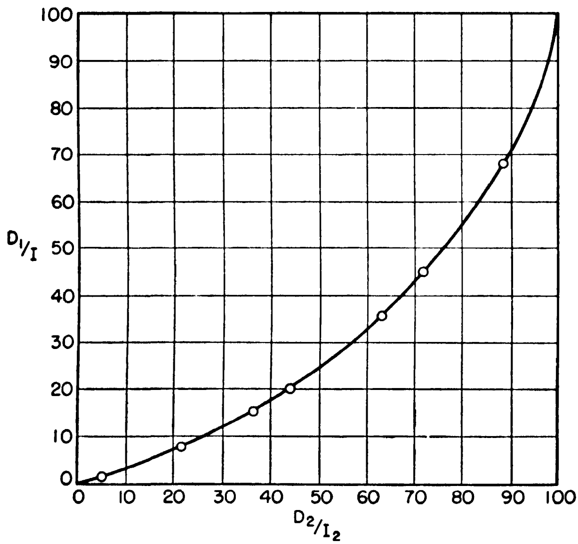


FIG. 7.36. Preliminary curve of intensity-step calibration.

the intensity of light emitted, a curve must be developed that gives the relationship in the following formula:

$$\log \frac{D_1}{D_2} = r \log \frac{I_1}{I_2}$$

where D represents the density, I is the intensity, and r is equal to the gamma of the plate.

To plot the gamma or calibration curve, choose a position on the cal-

culating board so that 20 on the vertical log scale is centrally located. Set the horizontal ruler so that 0.4 at the left end is at the edge of the vertical scale. Then the densities are plotted on the ordinate and the intensities on the abscissa, as shown in Fig. 7.37.

Mark a dot on the graph paper at 20 on the vertical scale. Move the vertical scale to the right until the edge is set at 0.8 on the horizontal

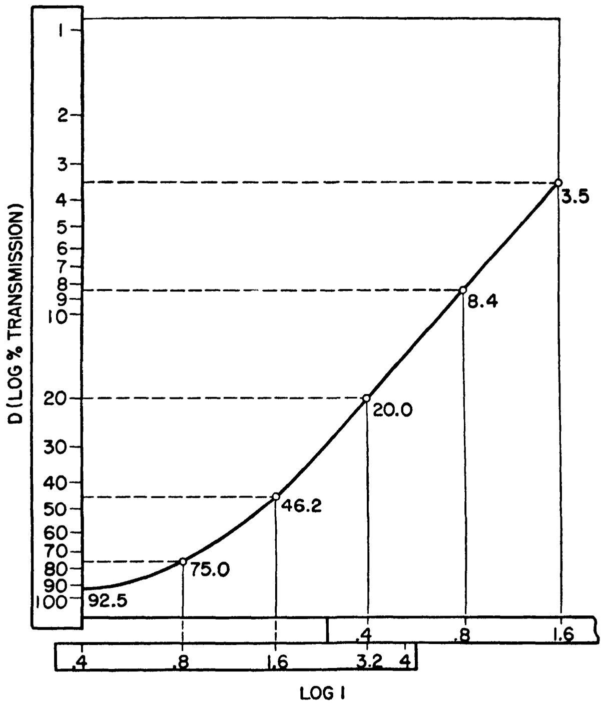


FIG. 7.37. Gamma or calibration curve.

scale. This doubles the intensity on the abscissa. Now the density that results when the intensity is doubled must be found. Referring to the curve shown in Fig. 7.36, 20 on the D_2/I_2 scale is equal to 8.4 on the D_1/I scale. Plot this value on the vertical log scale. Move the vertical scale to 1.6 on the horizontal ruler. Then 8.4 on the D_2/I_2 scale is equal to 3.5 on the D_1/I scale. Plot this value on the vertical log scale.

Next, the density values that result from decreasing the intensities by one-half of their value must be plotted. Set the vertical scale at 20 and the horizontal scale at 3.2. Referring to Fig. 7.36, 20 on the D_1/I scale is equal to 46.2 on the D_2/I_2 scale. Move the vertical scale to the left and plot 46.2 at 1.6 on the horizontal scale. Find 46.2 on the D_1/I scale.

This is to be equated to a value on the D_2/I_2 scale, which is found to be 75.0. Move the vertical scale to 0.8 on the horizontal scale and plot 75.0 on the vertical scale. Find 75.0 on the D_1/I scale and note its equivalent, 92.5, on the D_2/I_2 scale. Move the vertical scale to 0.4 on the horizontal scale and plot 92.5.

TABLE 7.20. SPECTROGRAPHIC PROCEDURES FOR SOME TYPICAL ALLOYS WHEN USING A-C SPARK EQUIPMENT

Alloy designation	To determine	Voltage		Power, kva	Capacitance, μf	Inductance, mh	Prespark time, sec	Exposure, sec	Hartman slide, mm
		Input	Primary						
Aluminum alloys:									
SC6, S9, 17-S.......	....	220	85	2.0	0.021	1.44	10	10	2.0
218 (Alcoa)........	....	220	85	2.0	0.021	1.08	10	10	2.0
Aluminum shot.....	Mg and Cu	220	85	2.0	.....	1.44	10	10	2.0
	Pb, Sn, Cd *	...	..	...	.....	....	5.0	90	3.0 †
Magnesium alloys:									
Dow R-IB.........	Cu, Si, Mn, and Zn	220	80	4/3	0.014	1.44	10	30	3.0 †
	Al	220	80	2/3	0.007	1.44	10	10	3.0 †
Zinc alloys:									
XXIII............	Al, Cu, Mg	220	85	2/3	.....	1.44	10	15	3.0
	Pb, Sn, Cd ‡	...	..	...	.....	....	5.0	90	2.0

* Using a-c arc equipment at 5,000 volts, 2.0 amp. An intensity step sector is used to give full and one-half intensity, and the impurity lines at full intensity.

† The intensity step sector is used with magnesium and with zinc to give two intensity steps.

‡ Using a-c arc equipment at 5,000 volts, 2.0 amp.

Connect points 20, 8.4, and 3.5, all of which should be in a straight line. Set the vertical scale so that it intersects the line drawn to connect the above-mentioned points at a reading of 15.0. Set the horizontal scale at 3.2. Find 15.0 on the D_1/I scale and determine its equivalent on the D_2/I_2 scale, which is 34.2. Move the vertical scale left to 1.6 on the horizontal scale and plot 34.2. Locate 34.2 on the D_1/I scale and find its equivalent on the D_2/I_2 scale. Move the vertical scale to 0.8 on the horizontal scale and plot the value found. Proceed in this manner to find and plot the value at 0.4 on the horizontal scale.

To secure additional points for plotting the curve, set the vertical scale so that 10.0 intersects the straight-line connection the first three points plotted. Set the horizontal scale so that 3.2 coincides with the edge of the vertical ruler. Proceed to find the densities for 1.6, 0.8, and 0.4 as described above.

The Working Curve. The basis of quantitative spectrographic analysis is the measurement of the intensity of the spectral line of the sought-for constituent relative to a line of a second component that is present in a

constant amount. The second component, or internal standard, may either be added to the sample or be an original principal constituent. In the latter case, the percentage of the principal constituent is sufficiently high so that it may be considered to be independent of the percentage variations of the other constituents. For example, in an aluminum alloy aluminum may be regarded as present in a constant amount. It is considered independent of the other constituents, namely, iron, copper, silicon, magnesium, manganese, and zinc. The reason for measuring the intensity of a given spectral line relative to the intensity of a line of the internal standard is to cancel the effect of variations in the spectrographic procedure.

TABLE 7.21. SPECTRUM LINES OF COMMON DIE-CASTING ALLOYS

Alloy	Spectrum lines, angstroms *									
	Fe	Cu	Si	Mg	Mn	Zn	Al	Pb	Sn	Cd
Aluminum alloys:										
SC6(ASTM).....	3020.5	2369.8	2435.16	2790.8	2949.2	3345.0	3050.07			
S9(ASTM)......	3020.5	3273.94	2435.16	2852.1	2949.2	3345.0	3050.07			
17-S(Alcoa)......	2739.55	2369.8	2881.6	2779.9	2933.06	3345.0	3050.07			
218(Alcoa)......	2739.55	3273.94	2881.6	3336.69	2933.06	3345.0	3050.07			
Al Shot.........	....	2369.8	....	2779.9	....	....	3050.07			
							3054.7 †	2833.1	2840.0	2288.0
Zinc alloys:										
XXIII..........	....	3273.94 (Step 2)	....	2852.1 (Step 2)	....	3075.9 (Step 1) 2670.57 †	3082.2 (Step 1)	2833.1	2840.0	2288.0
Magnesium alloys:										
Dow R-IB......		3247.0 (Step 1)	2516.12 (Step 2)	3329.23 (Step 1)	2949.2 (Step 1)	3345.0 (Step 1)				

* One angstrom unit equals 10^{-8} cm.
† This line used as internal standard with a-c arc to determine tin, lead, and cadmium.

The suitability of the reference line depends upon the fact that it must respond to varying conditions in the same way as does the line with which it is compared. Since the intensity of the given line varies with the concentration of the sought-for element, the intensity of the reference line should be as equal as possible to the intensity of the unknown line when the percentage concentration of the element is about average. The unknown line must be responsive to small changes in the percentage concentration. Since the gamma of the plate varies with wavelength, the internal standard line of the line pair should be chosen as near as possible to the wavelength of the unknown line. Thus, if the unknown and the internal standard line lie in the same wavelength region and

are of nearly equal intensity, no error can result in determining the intensity ratio, even if a large error is made in plotting the calibration curve. Only a slight error in the slope of the gamma curve can cause a large error in the intensity ratio if the difference in transmission readings of the lines is large. It therefore follows that if the reference line is due

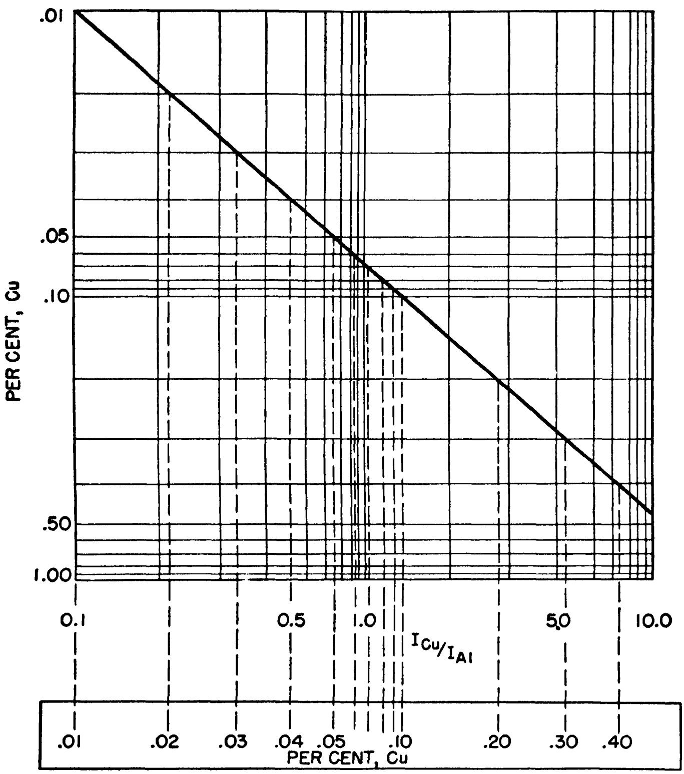


FIG. 7.38. Projection of a working curve on a calculating ruler.

to a principal constituent of the sample, then it must be chosen from among the weaker lines in the spectrum of the principal constituent.

The working curve is a plot of the percentage concentration on the ordinate against the intensity ratios of the desired constituents on the abscissa. To find the intensity ratio, set the transmission reading of the internal standard, which is aluminum in the case of an aluminum alloy, on the vertical log scale so that it coincides with the gamma curve. Set the index (10) of the horizontal log scale at the edge of the vertical log scale. Move the vertical scale so that the transmission reading of the desired constituent intersects the gamma curve. Read the intensity

ratio on the horizontal log scale. Values below the index are 0.4, 0.5, etc. The intensity value at the index is therefore 1.0, and those values above the index are whole numbers.

This procedure is carried out for a series of standards whose constituents vary over a considerable range of percentage composition. The intensity ratios are found for the elements to be quantitatively determined. As explained previously, the percentages are plotted on the

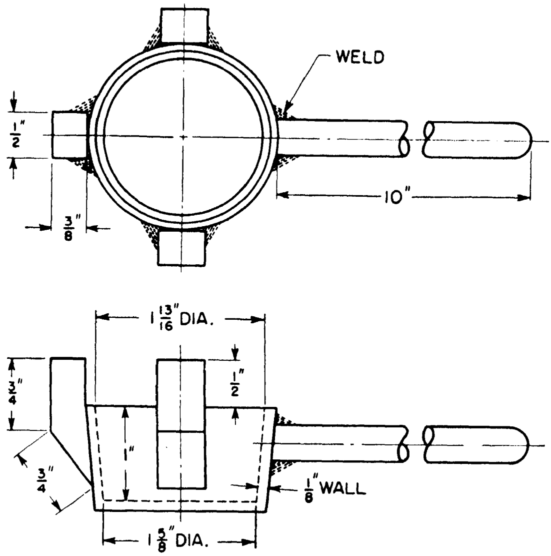


Fig. 7.39. Dimensions of steel mold used to obtain samples of metal from the casting machines and furnaces.

ordinate and the intensity ratios on the abscissa. Standards may be either prepared or purchased from several known sources or they can be made in the plant laboratory for daily calibration of index points.

It is desirable to have a ruler upon which the percentages of the elements are projected from the working curves. Therefore a blank ruler is substituted for the log scale, and the vertical scale is set on the working curve. The percentages may then be marked on the blank ruler. The percentage scales are first marked with a pencil and then are cut in with a penknife. The percentages are stamped on the board with steel stencils and the impressions penciled to make them more legible. The board shown in Fig. 7.38 is finally given a coat of shellac.

Obtaining the Sample. Metal from the casting machines and furnaces is poured into steel molds (Fig. 7.39) to furnish samples for the laboratory. Three small "knockers" are welded on the mold to facilitate the

removal of the sample. The samples are water-chilled soon after solidification. The samples are then faced on a high-speed lathe. It is very important that the resulting surface be very smooth, since the spark or arc has a tendency to concentrate on any small points or ridges protruding above the general surface. This condition affects the intensity ratios, especially of the elements of higher percentage concentration.

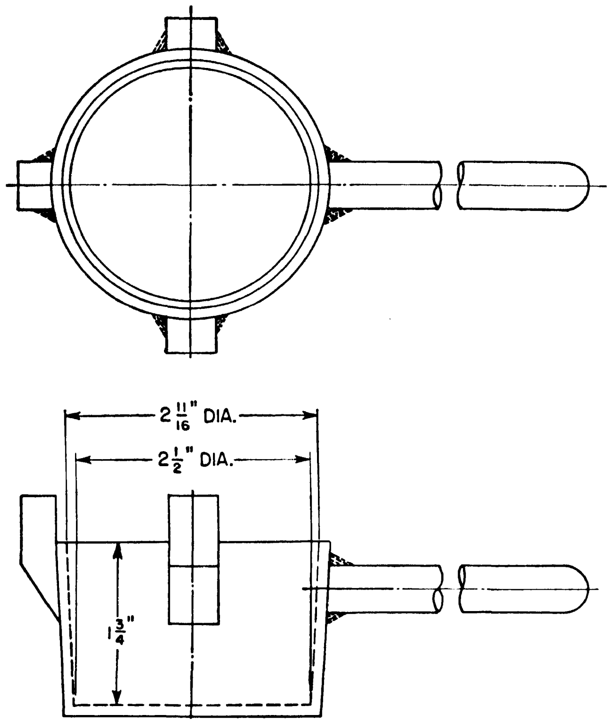


FIG. 7.40. Dimensions of steel mold used for pouring spectrographic standards.

The mold used for pouring spectrographic standards is similar in every respect to the sample mold except for its dimensions. The molds may be made from machine steel. A drawing of the standard mold is shown in Fig. 7.40.

Exposure and Development of the Plate. When a plate of samples is taken, two or three standards are exposed so that their positions on the plate are between a nearly equal number of samples. Thus, the standards represent an average of the spectral conditions under which the samples were taken.

The exposed plate is developed in the plate-developing machine, which

contains three trays. The first tray contains D-19 developer, the second a solution of 5 per cent acetic acid, and the third a solution of X-ray fixer of the same strength as that used for the fixation of X-ray films. The plate is developed for 3 min, placed in the acetic acid stop bath for 5 sec, and in the fixer solution for double the time required to clear the plate. Each tray contains 800 cc of solution, the temperature of which is maintained at 65°F by means of the thermostat.

After the plate has been fixed, it is placed on the plate washer for about 1 min, rinsed with distilled water, sponged nearly dry with a cellulose sponge, and finally placed on the plate drier.

Calculations. After the plate is read on the densitometer, the percentage composition of the alloys can be calculated. The index points of each sought-for constituent in the standards are determined and the average used for the calculations. The index point is determined in the following manner. Set the densitometer transmission reading of the constituent on the gamma curve by means of the vertical log scale. Set the percentage ruler so that the percentage of the particular constituent coincides with the line on the vertical log scale. Move the vertical scale and set the transmission reading of the internal standard line on the gamma curve. The line on the vertical log scale now gives the position of the index point on the percentage ruler.

To calculate the percentage of the desired constituent, set the transmission reading of the internal standard on the gamma curve. Set the index point found above to the line of the vertical log scale. Move the vertical log scale so that the transmission reading of the desired element is set on the gamma curve. Read the percentage on the percentage ruler as indicated by the line of the vertical log scale.

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CHAPTER 8

FINISHING OF DIE CASTINGS

The principal reasons for finishing die castings are (1) to improve appearance and enhance sales appeal; (2) to protect the base metal against corrosion by moisture and other corrosive media; and (3) to increase surface smoothness so that the castings can be kept clean and sanitary. While these are the important reasons, there are, of course, other minor ones, such as to increase light reflectance or to improve marproofing or sound damping of the surface.

The various types of finishes that may be used for these purposes can be classified under the following headings:

1. *Mechanical finishes,* developed by abrading or working the casting surface by mechanical means to obtain a polished or textured effect.
2. *Chemical finishes,* produced by treating the castings with chemical solutions to produce etched surfaces or oxide coatings having a wide variety of properties.
3. *Electrolytic finishes,* formed by anodically oxidizing the casting in a suitable electrolyte to form a substantial oxide coating. The oxide coating may then be given supplementary sealing or coloring treatments.
4. *Electroplated finishes,* applied by the electrodeposition of metals such as copper, nickel, chromium, brass, gold, and silver.
5. *Paint and organic finishes,* applied by spraying, dipping, or brushing the casting with clear or pigmented coatings to obtain either a conventional or a novelty finish.
6. *Metallic finishes,* added to the die-cast surface either by spraying molten metal on the casting or by dipping the casting in a metal bath.

The selection of a finish to be used alone or combined with another finish for any die casting will depend upon such factors as sales and service requirements, cost considerations, the design of the casting, the size and shape of the casting, and the type of alloy that is to be used. When no background of experience exists, it is advisable for the user to consult experts in the field, such as the die caster, an experienced jobbing finisher, the finishing departments of primary alloy producers, or the suppliers of finishing materials, before reaching a decision.

"As-cast" Finish. Of course, the type of finish that is specified governs to a large extent the care with which the part must be cast. It is extremely important that a definite specification for cast finish be set up and shown on the blueprint and all job records. It is equally important that the machine operators know the purpose and limits of each

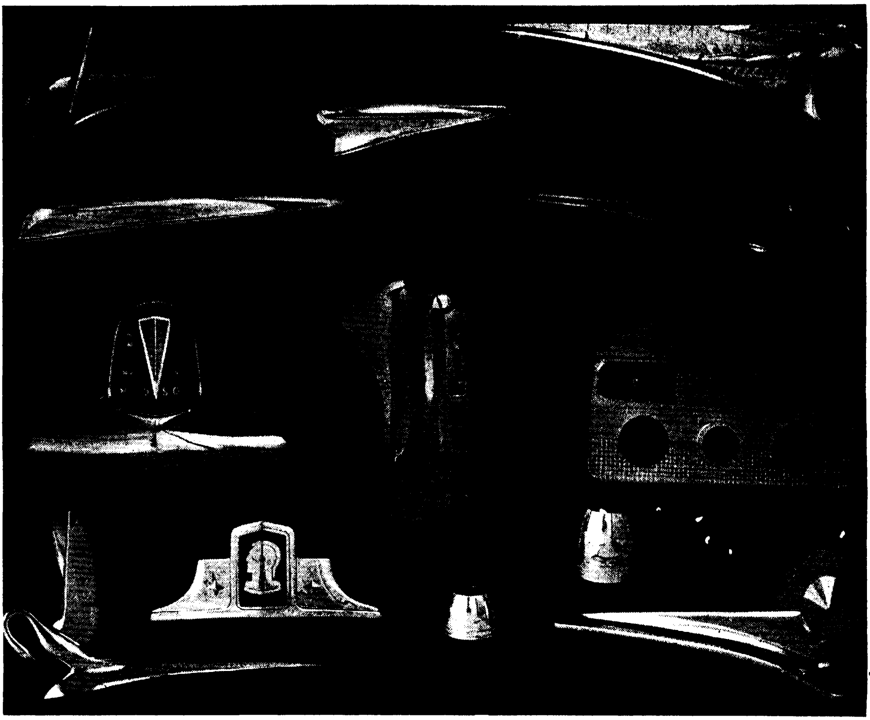

Fig. 8.1. Chromium-plated zinc die castings for the automotive industry. Such castings must have a first-class hardware finish, which means that only buffing is necessary before plating.

type of finish and have information about the requirements of the job on which they are working.

Following is a description and examples of five types of finish which cover the range normally encountered in die casting:

First Class: "Hardware" Finish. "Hardware" finish is a term used in the industry to indicate the ultimate in cast surface condition—a surface absolutely smooth and free from all defects such as run marks and pits. The parting lines must be evenly matched and solid. Cave-ins and low spots in the parting lines are not acceptable. Solder, scale, heat spots, and waves are not permissible.

With this type of finish, only the removal of parting lines by a normal 220-grit operation and the removal of the natural oxide film by a simple buffing operation are necessary before the casting is ready for plating.

Most parts requiring a hardware finish are used primarily for ornamentation and are generally capable of being automatically buffed (Fig. 8.1).

Examples are automotive hardware, trim, ornaments, bezels, refrigerator handles, and plumbing handles and fixtures.

Second Class: Secondary Plating Finish. This type of cast surface finish is usually specified for die castings of such size and complexity

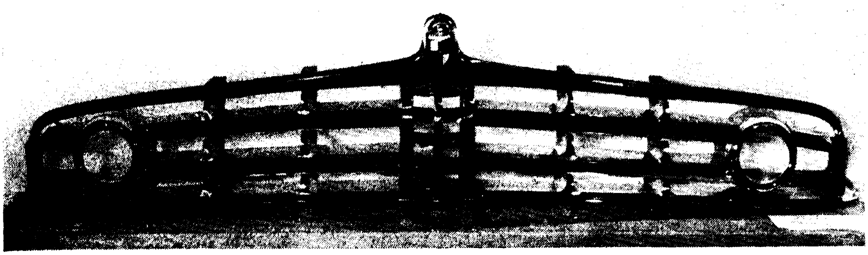

FIG. 8.2. Large castings like the one shown here that are to be plated are cast with a second-class finish. Spot polishing normally is required prior to plating to remove surface blemishes.

that it is impossible to obtain a hardware type of finish over the entire surface. Normally, spot polishing with 220 abrasive in certain remote areas is necessary to remove surface blemishes that cannot be removed by simple buffing treatment.

Slide, scale, solder, heat waves, and small, light surface run marks are permissible. Cave-ins and low spots at parting lines should be held to an absolute minimum. Pin holes and slight surface porosity that can be easily removed during the polishing operations may be acceptable.

Examples are large automotive radiator grilles, steering-wheel hubs, and camera and optical parts (Fig. 8.2).

Third Class. A surface finish of this type might be termed "fairly good finish," suitable for nonornamental parts that are plated or for parts that are to be lacquered. The surface should be spot-polished as required. Light scale, solder, heat spots, waves, and shallow surface porosity may be acceptable. Small pin holes at the gated sections and light porosity at the parting lines are also acceptable, as are cave-ins and low spots along parting lines.

Examples are food-mixer housings and parts, tone arms and other radio parts, and business-machine parts.

Fourth Class: Paint Finish. Castings in this class are ones on which a paint filler is to be used to fill in surface defects before the application of final paint coats or on which novelty paint finishes, such as crackle, wrinkle, or Pebl-Tone, will be used to cover surface defects. Surface imperfections such as slight run-marks, cold shuts, and surface porosity are acceptable, as are small cave-ins and low spots at parting lines.

Examples are oil-burner equipment and instrument housings (Fig. 8.3).

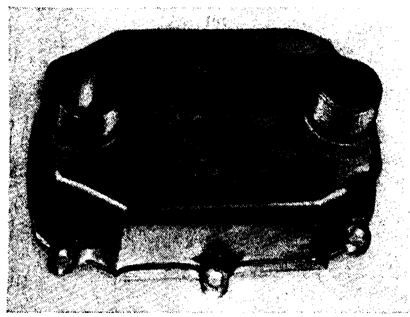

FIG. 8.3. Meter housing having a fourth-class finish. A fine surface finish is not so important on parts that are to be painted.

Fifth Class: Mechanical. This class of finish is specified when the surface condition of the casting is of less importance than the internal soundness and strength or when the surface is to be machined before assembly. Naturally, holes, heat spots, and internal unsoundness as determined by radiography are not acceptable.

Examples are carburetors, fuel pumps, outboard motors, cylinder heads, blocks and crankcases, and automotive transmission parts.

FINISHES FOR ZINC-BASE ALLOYS

The need for finishing zinc-alloy die castings is based on the desire for decorated effects and the need for protection against special types of corrosive attack. Plated metallic, plated nonmetallic, immersion metallic, and nonmetallic coatings, as well as organic finishes, may be used for either or both of these purposes. Mechanical finishes, such as polishing or buffing, are seldom used for zinc die castings, except when necessary to prepare them for subsequent plating operations; zinc-base alloys oxidize quite rapidly on exposure to air, so that if plating or painting are unnecessary, they are usually used in the as-cast condition.

Electroplated Finishes for Zinc. An electroplate is, perhaps, the most common finish for zinc die castings (Fig. 8.4). Two important factors regulate the quality and durability of the electrodeposited coatings, namely, the condition of the surface of the die casting as produced and its condition when prepared for plating. The as-cast surface of die castings must be sound and free from surface porosity, sponginess, run-marks, and similar defects, if a high-quality, endurable coating is to be obtained. Plating failures such as premature blistering can often be

traced to pits and similar defects in the casting. Therefore, as one prime factor in quality plating, a great deal more care in fabrication and inspection must be given to die castings that are to be electroplated than to those that are to be finished by other methods. The casting conditions such as gating, venting, pressure, metal and die temperatures, and lubrication must be carefully coordinated to produce the maximum soundness of surface.

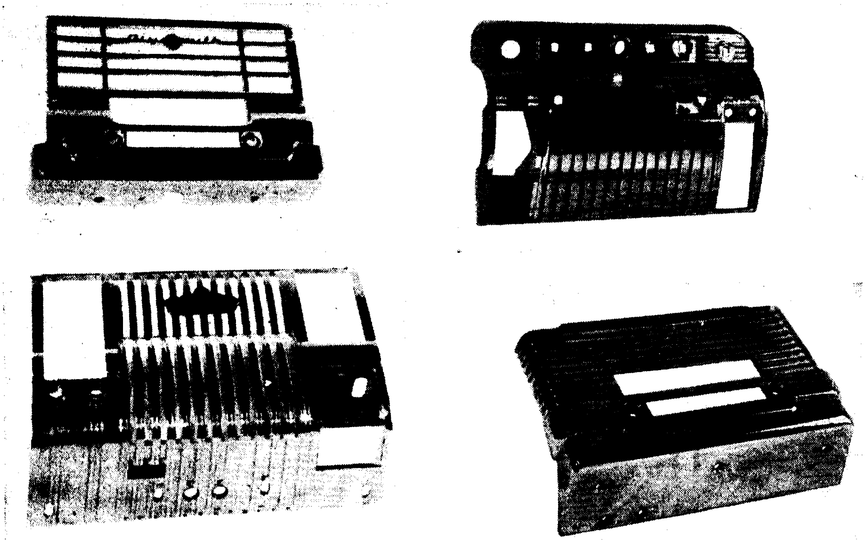

FIG. 8.4. Automotive radio grilles. Since a large portion of the zinc die-casting tonnage goes to the automotive industry, chromium electroplate is a widely used finish.

Castings designed for electroplating finishes usually can be produced with surfaces sound enough to require only buffing with a rag wheel, although in large and intricately shaped castings, this may not be possible. Gated sections and parting lines necessarily have to be polished on an oil wheel, but on the remainder of the casting it should be necessary only to buff. Polishing is done on leather, felt, or canvas wheels to which is glued emery of mesh varying from 140 to 180, depending upon the amount of surface to be removed; polishing may also be done with an endless abrasive strap.

Buffing. Buffing is done by manually or mechanically forcing the casting against a cloth wheel that is coated with an abrasive compound called

tripoli. This compound cuts and colors the casting and brings the surface to a high finish in one operation. Many types of sewed wheels are utilized to obtain either a long wheel life or an improved finish. Also, the contour or design of the casting affects the choice of the type of sewing, speed of wheel, and direction of travel to be used; and whether or not the part lends itself to hand or mechanical buffing.

Barrel Polishing and Buffing. Many small parts lend themselves to barrel polishing and buffing, sometimes termed *burnishing* (Fig. 8.5).

FIG. 8.5. Burnishing department. Burnishing or tumbling is practical only for the smaller zinc die castings.

The factors that determine whether castings are to be burnished or buffed are (1) size and number of pieces; (2) finish required, since in burnishing, some castings will impinge on each other to such an extent that the marks show after plating; (3) weight and design; (4) size and number of holes or pockets, since holes may cake or fill with burnishing compound; and (5) whether or not the parts are threaded (inside threads are usually not damaged).

Cleaning and Racking. After the usual polishing and buffing operations, the polishing compounds are removed by degreasing the castings, either with trichlorethylene or solvent-type cleaners containing emulsifying agents, and by washing them in an alkaline spray that mechanically removes the remaining traces of tripoli. The castings are then cleaned anodically for from 15 to 30 sec for removal of the last traces of grease or buffing compound binders (Fig. 8.6).

The cleaners may be quite alkaline and should not contain more than

5 to 10 per cent silicates to aid subsequent rinsing. After cleaning, the castings should be rinsed in both warm and cold water to remove all traces of the alkali and then dipped in an acid solution. The acid bath usually consists of $\frac{1}{2}$ to 2 per cent sulfuric acid by volume; the time of immersion is from 10 to 20 sec, or until the evolution of gas is noticeable. With this cycle, a minimum amount of hydrogen is absorbed by the zinc, which is desirable because excessive absorption of hydrogen results

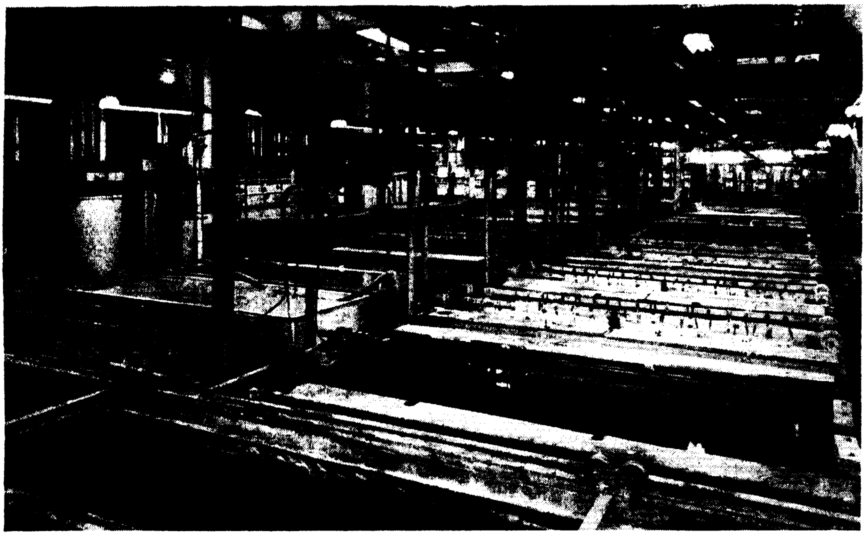

FIG. 8.6. Section of a large plating installation showing cleaning and plating tanks.

in poor adhesion and, in the case of painted surfaces, a tendency toward blistering.

Proper racking of the castings for cleaning and plating is extremely important. Each rack should be especially designed to meet the conditions under which the plating of the parts is to be performed (Fig. 8.7). Consideration must be given to the following points so that a sound, uniform plate is obtained:

1. *Contour of the part.* Recessed sections must be so positioned on the rack that all sections are exposed to similar current densities. Even so, special anodes, such as bipolar anodes, must be used in some cases to obtain even distribution in remote or recessed areas.
2. *Current requirements.* The current requirements for each rack must be accurately known so that contact points and splines have the proper cross section to carry the current without building up high electrical resistance.

3. *Gas liberation and drainage.* Parts must be placed so that gases liberated in the cleaning and plating operations are not pocketed, and so that the plating solution drains from the pockets.

Racks are generally constructed of copper. The parts of the rack that extend below the solution level are usually covered with Koralac-vinyl-plastisols or similar materials.

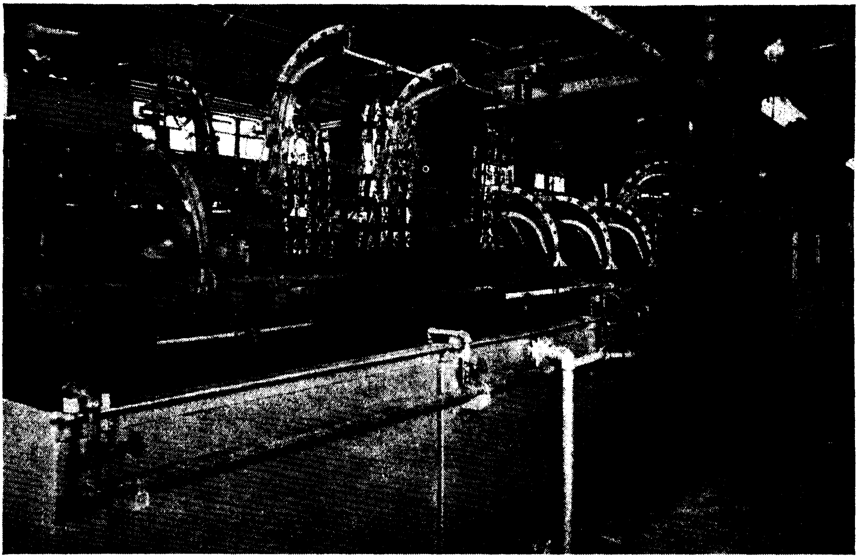

FIG. 8.7. Automatic plating line for small parts. Racks designed for such parts must be good in order to get the plate evenly distributed on all surfaces.

Types of Electroplates. Chromium plating, because of its tarnish resistance, high luster, and hardness, is the most popular finish applied to zinc die castings. Chromium can be applied directly to the metal, but such coatings are porous and do not stand up under outdoor exposures. For any type of exposure other than indoor, it is necessary to deposit other metals on the castings prior to applying the finishing coat of chromium. Dual plates of copper and nickel have been found most suitable. When service conditions are not too severe, a single undercoat of nickel may be satisfactory.

The plating of copper directly on zinc is complicated by diffusion between the copper plate and the zinc-base alloy. Extremely thin deposits of copper may be completely absorbed in relatively short periods of time. Therefore it is necessary to guard against thin deposits and always specify a minimum thickness of copper. It has been found that a thick-

ness of 0.0002 in. of copper is satisfactory,[10] * although, as a safety measure, a minimum thickness of 0.0003 in. usually is specified. Such copper deposits followed by a heavy nickel plate having a minimum thickness of 0.0003 in. will give excellent results, provided that all precautions as to the plating procedure are observed.

Copper is first applied as a strike from a cyanide bath, after which the casting is plated from a highly concentrated cyanide solution containing a brightening agent. The compositions of these baths are given in Table 8.1. Current density and time are carefully regulated. Uniform,

TABLE 8.1. TYPICAL COPPER-PLATING BATHS

Type of plate	Composition of bath *		Bath temperature, °F	Operating voltage	Minimum plating time, sec
	Material	Amount			
Copper strike	Copper cyanide	3.0 oz/gal	135 to 140	6.0 to 7.0	30
	Sodium cyanide	4.5 oz/gal			
	Free cyanide	1.0 oz/gal			
	Sodium carbonate	2.0 to 6.0 (max) oz/gal			
	Iron	2.0 g/l			
Copper plate	High-speed copper salts †	1.5 lb/gal	170 to 180		
	Potassium hydroxide	0.35 lb/gal			
	Antipitting agent	0.42 lb/gal			
	Copper	5.5 to 6.0 oz/gal			
	Free cyanide	2.25 to 2.5 oz/gal			

* Colorimetric pH of bath should be between 11.5 and 12.5.
† Manufactured by E. I. du Pont de Nemours & Co., Inc.

nonporous deposits are obtained at a speed approximating 0.002 in. in thickness per hour.

The cathode is mechanically agitated in the plating bath. Anodes are of electrolytic copper.

Bright nickel electroplates add a lustrous effect that enhances the appearance of the castings and obviate the need for buffing or coloring the copper plate prior to the deposition of other metals. The thickness of nickel deposits may range from 0.0003 to 0.001 in. Various brightening agents are added, the types depending upon which of the patented procedures for bright nickel plating is used; the composition for a typical nickel-plating bath is given in Table 8.2. Both sulfuric acid and nickel carbonate are used to regulate the acidity of the bath. Anodes are of nickel and are usually enclosed in cloth bags to prevent loose particles from breaking away from the anodes and adhering to the cathodes, thus causing roughness of the plate.

* Superior numbers refer to Bibliography at the end of the chapter.

TABLE 8.2. TYPICAL NICKEL-PLATING BATH

Composition of bath *		Bath temperature, °F	Operating voltage, † volts	Plating time, ‡ amp-hr
Material	No. of oz/gal			
Nickel sulfate	40.0	140 to 150	6 to 9	1,150
Nickel chloride	8.0			
Boric acid	6.0			

* Wetting agent used to prevent pitting; use of brighteners dependent upon proprietary nickel bath.

† Operating voltage dependent on current density required and anode-to-cathode distance. Average current density ranges from 40 to 50 amp/sq ft.

‡ Average plating time to deposit 0.001-in. plate.

Recapitulating then, a typical sequence of operations for electroplating zinc-base die castings is as follows:

1. Strapping or polishing with a 120- to 200-grit abrasive to remove parting lines.
2. Buffing on a cloth wheel coated with tripoli compound.
3. Degreasing in a vapor-phase trichlorethylene degreaser.
4. Electrolytically cleaning in a suitable alkaline cleaner, making the casting the anode.
5. Rinsing thoroughly in both warm and cold running water.
6. Dipping in an acid solution consisting of ½ to 2 per cent sulfuric acid by volume.
7. Rinsing in clean running water to remove traces of acid.
8. Applying a copper strike by immersing the casting in a cyanide bath.
9. Copper plating in a concentrated cyanide solution containing a brightening agent and nonpitter.
10. Rinsing in hot and cold running water.
11. Depositing a bright nickel plate from 0.0003 to 0.001 in. thick.
12. Rinsing in hot and cold running water.
13. Chromium-plating to the required thickness.

Extensive experimental work and practical service tests have shown that minimum thickness of the copper, nickel, and chromium plates is necessary for each type of application, environment, and condition of use. These minimum thicknesses are given in Table 8.3, which lists the

three types of electroplated finishes most commonly used on zinc alloys. That the finish designated as FZ is the highest quality electroplate is apparent by its resistance to corrosion as shown by the standard salt-spray test (ASTM B117). Type KZ is an intermediate-quality finish, but the one most generally applied for outdoor exposure and general service; type QZ is recommended only for interior use.

TABLE 8.3. PLATED-CHROMIUM FINISHES FOR ZINC-BASE DIE CASTINGS *

Designation of finish	Corrosion resistance (salt-spray test), hr	Minimum thickness of plate, in.			
		First coat, copper	Second coat, nickel	Total, copper plus nickel	Final coat, chromium
FZ	48	0.0004	0.0005	0.00125	0.00001
KZ	32	0.0003	0.0003	0.00075	0.00001
QZ	16	0.0002	0.0003	0.0005	0.00001

* As given in ASTM B142-45T.

In addition to these finishes, zinc-base die castings may be plated with bronze, silver, gold, and other metals. In finishing with these metals, it is essential that the primary coats of copper and nickel of required thickness be deposited before electroplating. With this procedure, durable finishes will be obtained.

Chemical control of the plating room is the best means of securing uniform deposits of metal. All acid solutions should be analyzed every day for acid content, and all alkaline cleaners should be checked for carbonate and hydroxide content. The copper solutions should be analyzed once a day for copper content, free cyanide, and carbonate content. Nickel solutions should be checked twice a week for nickel content, chloride content, sulfate content, and boric acid. The pH value of all nickel solutions should be determined twice a day. Additions to the plating solutions should be made immediately upon receiving the analysis.

In addition, the thickness of copper and nickel on plated articles should be determined every day (Fig. 8.8). The thickness tests can be arranged so that every piece is checked for thickness once a week. The thickness is determined by polishing and etching a plated specimen and examining it under a microscope having a calibrated eyepiece. The sample to be checked is fastened in a clamp so that the surface to be polished is at right angles to the plated surface. It then is ground on 120-mesh emery

paper until saw marks have been removed, and then on emery paper No. 1 (at right angles to marks left by the rough emery cloth) until all scratches have been removed. Finally, the sample is polished on emery papers Nos. 0 and 00 in the same way and then, with polishing alumina, on a broadcloth wheel rotating at 1,700 rpm; the surface is washed off between each polishing operation. Then the sample is etched with

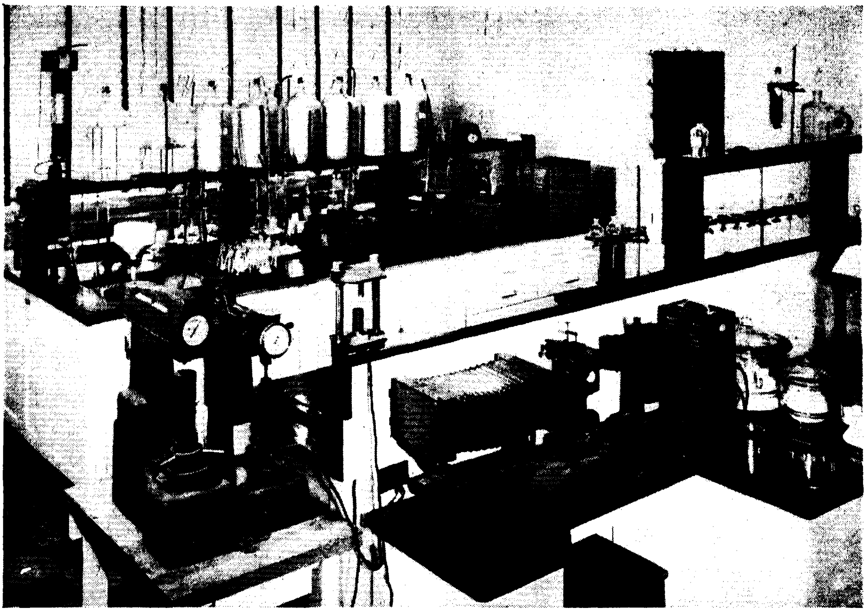

FIG. 8.8. Control laboratory for a plating department. Thickness and hardness of plate and concentration of the plating and cleaning solutions must be periodically checked.

$NH_4OH \cdot H_2O$ etching solution, and the parts examined under a microscope. Three or four samples can be examined at one time by clamping them together. This method is essentially the same as that described by C. E. Heussner in *The Monthly Review of the American Electroplaters' Society*.

Electroplated Nonmetallic Finishes for Zinc. There are several methods by which semimetallic or nonmetallic decorative coatings can be produced on zinc-alloy die castings by the use of an electric current.

*Moly Black Process.** This black-plating process produces a black lustrous coating that is suitable for protective and decorative purposes. The plating is rapid: a plate of 0.001-in. thickness can be deposited in

* Patented process of United Chromium, Inc.

about 10 min. The usual nickel-plating equipment can be used, and the process is easily installed, maintained, and controlled. The moly black plating solution is made up and maintained from prepared salts. Unlike other solutions used for black plating, it is not sensitive to slight changes in operating conditions.

*Electrocolor Process.** *Electrocolor* is the trade-marked name of a process that can be used to produce films of innumerable color combinations on metallic surfaces. These colors are produced in a plating bath consisting of water and copper salts. The casting serves as the cathode or negative pole, and copper is used for the anode or positive pole. The deposit consists chiefly of copper oxide. The bath is operated at low voltage (approximately 0.40 volts), with a current density of approximately 0.5 amp/sq ft. The length of time of plating may run from 1 to 30 min, dependent upon the color or depth of color desired.

All the colors produced by this process are obtained from one plating bath, the color being a function of the length of time that the article remains in the bath. As the length of time of plating increases, the color changes successively from violet to blue, green, yellow, and red. The color changes as the plating is continued, but with each succeeding cycle, the color becomes deeper and darker.

The condition of the metal surface before plating also determines the final shade and luster. A highly polished surface gives a bright finish, and a scratch-brushed surface gives an eggshell finish. Different colors also are obtained on different metal bases, such as on plated deposits of copper or nickel; in any case, zinc die castings to be colored by this process must first be plated with either copper or nickel.

Various effects can be produced by special treatments. Two-tone effects are obtained by stopping off a part of the area to be colored for a part of the cycle. It is also possible to obtain combinations of chromium plate and color by stopping off parts of the casting prior to chromium plating and then coloring the exposed portions, leaving that part which is chromium-plated unaffected.

Since the colors obtained by this process are of film thickness only, it is absolutely necessary to cover them with a clear lacquer to ensure protection against oxidation, corrosion, and wear; as long as the color plate is protected in this manner it will not fade on being exposed to sunlight. However, it is apparent that the primary use of this treatment is for decoration. It does not possess great wear resistance and should not be used on parts subjected to wear or to outdoor exposure. It is usually applied to clock cases and bases, novelties, boxes and reuse containers, statues, and similar ornaments.

* Patented process of United Chromium, Inc.

*Anozinc Coatings.** *Anozinc* is a registered trade-mark for special compounds used to produce protective anodic coatings on electrodeposited zinc and zinc-base-alloy die castings. There are two types of Anozinc finish: yellow and black. Both of these finishes have good corrosion resistance and are attractive in appearance. They are applied primarily to ornaments and novelties.

Chemical Finishes. Many zinc-base die castings are finished simply by immersing them for short periods of time in a chemical solution. Some of these treatments are for decoration and some for inhibiting surface corrosion; while others are used primarily to prepare the surface

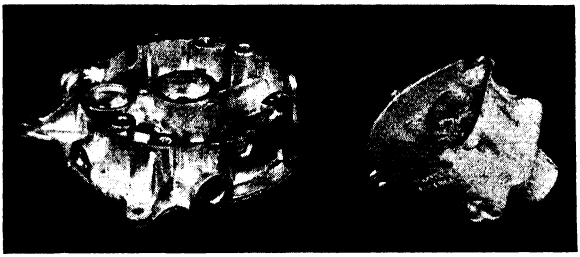

FIG. 8.9. Die casting that has been Cronak-treated to inhibit oxidation.

of a casting for paint finishes. The color, cost, and protective value of the coating depend upon the type of treatment that is selected.

*Cronak Process.** Zinc die castings for mechanical devices such as automotive carburetors, automotive fuel pumps, and washing-machine parts (Fig. 8.9) are usually used in the as-cast condition without any treatment. In moist atmospheres, however, unprotected zinc castings may acquire a coating of zinc oxide and hydroxide, which in applications such as those just mentioned affects the operation of the part. Such surface corrosion may be inhibited by an immersion treatment in certain water solutions of alkali dichromates.

For such a treatment, known as the *Cronak* treatment, a solution containing the following proportions is used: 200 gm of sodium dichromate, 6 cc of concentrated sulfuric acid to 1 l of water. This solution is best contained in earthenware crocks or in refractory-lined tanks, and its temperature should be kept close to room temperature.

When using this treatment, it is essential to start with a cleaned casting free from oil, grease, and other foreign matter. The casting may be given a mild alkaline cleaning treatment similar to that used regularly in electroplating. After a 15-sec dip in the solution, the casting should

* Patented process of the New Jersey Zinc Company.

be dried as quickly as possible without the use of heat; a blast of cold air is the most satisfactory drying medium.

The efficacy of this treatment in inhibiting corrosion may be demonstrated by immersing both a treated and an untreated casting in ordinary water. After a week or so, a sediment of white zinc corrosion products will show on the untreated casting, while the treated casting will remain free from attack indefinitely.

*Iridite Process.** *Iridite* is another chemical treatment produced by immersing the casting in a dichromate solution. This treatment is designed to put an olive-drab film on zinc parts to be used by the armed services. Originally applied to galvanized iron, it does not work so well on zinc alloys containing aluminum. Hence, it is necessary to apply a thin, electroplated coating of zinc to the casting before dipping it into the Iridite solution.

Other Proprietary Processes. Besides the widely used treatments just described, there are two other groups of proprietary processes that are used to (1) enhance the appearance of die castings, or (2) improve the adherence of paint finishes on die castings. In the first group are such treatments as *Ebonol Z,*† *Black Magic,*‡ and *Unichrome Dip,*§ any of which can be used to put a low-cost, jet-black finish on zinc die castings. In the latter group are such treatments as *Parkerizing,* || *Bonderizing,*** and *Lithoform.*†† All the solutions for such treatments are sold commercially.

Organic Finishes for Zinc. Lacquers, enamels, paints, and other organic finishes often are applied to zinc die castings to improve their appearance (Fig. 8.10). An endless range of colors and textures can be used, either alone or in combination with electroplated deposits.

The newer types of organic finishing materials have excellent abrasion resistance, impact strength, and extensibility. They also have good adhering qualities and are capable of resisting the action of strong chemical solutions, gasolines, and oils. The proper preparation of the metal surface for the application of organic coatings is the most important item in the ultimate life of the coating. Three factors must be observed in preparing the metal surface:

* Patented process of Rheem Manufacturing Company.

† Patented process of Enthone Company.

‡ Patented process of Bradley-Mitchell Company.

§ Patented process of United Chromium. Inc.

|| Patented process of Parker Rust Proof Company.

** Patented process of Parker Rust Proof Company.

†† Patented process of the American Chemical Paint Company.

1. The metal must first be thoroughly cleaned in either alkaline solutions or organic solvents, depending upon the surface condition.
2. The surface should be roughened or etched to provide anchorage for the initial coating. Treatment by chemical solutions such as Bonderite, Lithoform, or similar phosphate solutions is one effective method of ensuring good adhesion of organic coatings. Sand-blasting the surface with a fine sand is also effective, not only for producing a

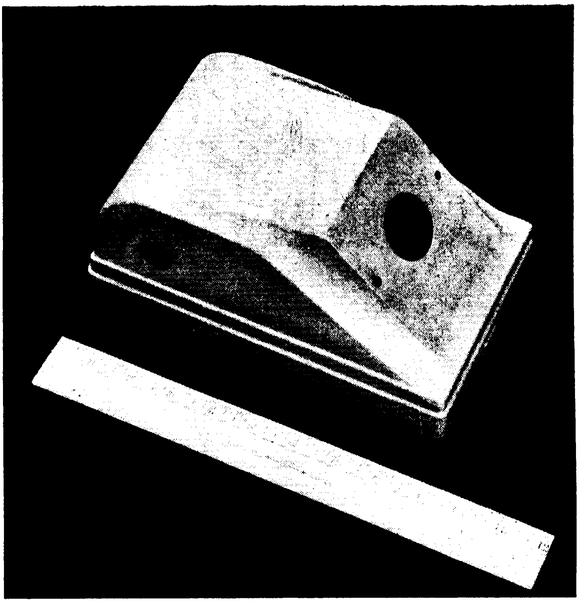

FIG. 8.10. Die-cast zinc telephone base prior to being enameled.

roughened surface but also for cleaning the metal of any extraneous matter.
3. The use of a suitable priming coat is advisable, since it inhibits corrosion, insulates the metal, and acts as a base for succeeding finishing coats. Primers may be of either the air-dried or the baked type, although the baked type is used more extensively.

The pigments used in the primers exert a great influence on the ultimate serviceability of a finish because of their anticorrosion properties. Zinc chromate or combinations of zinc chromate with other chromates, iron oxide, ammonium ferrous phosphate, or other pigments suspended in a synthetic resin vehicle, make good primers. Unpigmented phenolic-base primers have good chemical and moisture resistance. Alkyd-base primers, pigmented with titanium dioxide and used as undercoats for

white organic finishes, have good flexibility and adhesion. Aluminum powder or mixtures of it with other powdered metals have been used as the primer body for some applications. Regardless of the constituency, the primer must be compatible with the final coatings and have good adhesion to the base metal; and it should not soften or be otherwise affected by the application of subsequent finishing coats.

The finishing or final top coatings are chiefly for decoration. The materials used are usually lacquers or enamels; varnishes are also used to some extent.

Enamels are usually described as finishes consisting of pigments suspended in either a synthetic resin vehicle or a varnish, or in a mixture of the two. They may be either the air-dried or the baked types. The drying is accomplished through oxidation and/or polymerization, depending upon the type of vehicle used. The baking type requires temperatures ranging from 200 to 300°F, and drying times ranging from 15 min to 1 hr.

Lacquers consist of film-forming ingredients such as nitrocellulose, cellulose acetate, ethyl cellulose, butyrate, or vinyl resins mixed with other resins and plasticizers. Plasticizers are necessary additions to lacquers to supply the coating with flexibility and adhesion; they are solvent materials, such as tricresyl phosphate, that have a high boiling point. Resins are added to produce improved gloss, more body, or better adhesion. The fact that lacquers dry by evaporation of the solvents in which the vehicle is dissolved distinguishes them from enamels or varnishes, which are dried through oxidation and/or polymerization. Lacquers may be either clear or colored.

Varnishes are made up of natural or synthetic resin materials suspended in oil. They are dried by either oxidation or polymerization, depending upon the type of resin and oil used. They may be either air-dried or dried by baking. Varnishes frequently are used as a vehicle for enamels and other types of finishes, but they may be used alone for coating metal parts when a clear coating is desired, as in lithographic work.

Novelty Effects with Organic Finishes. A wide variety of special organic finishes have been developed that have, in addition to great sales appeal because of improved appearance or the novelty effect, some functional advantages, such as a textured pattern that dies surface roughness and imperfections. The principal types of these special finishes may be classified as follows:

Wrinkle Finishes. "Wrinkle" finish (Fig. 8.11) is the product of oil, resin, and drier ingredients, balanced so that when the surface is dried, usually by baking, it is ridged or wrinkled instead of being smooth.

Advantages of this type of finish include an ability to obscure surface defects, an attractive texture, and good durability. The chief objection to its application is that the wrinkled surface gathers and holds dust and dirt.

Crystal Finishes. These finishes are obtained by dissolving organic crystalline materials in a nitrocellulose or ethyl-cellulose solution whose solvents are so proportioned that the substance crystallizes on drying

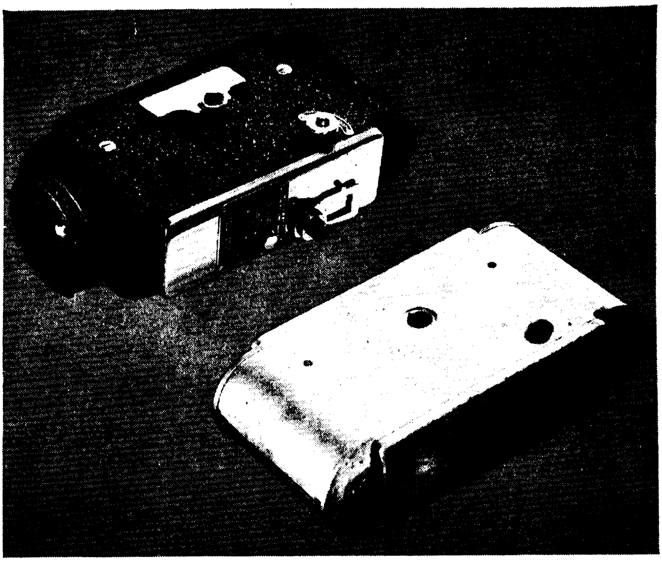

Fig. 8.11. Wrinkle finish applied to the zinc case of a motion-picture camera.

into a variety of beautiful effects. Best results are obtained with a one-coat finish, because it is difficult to obtain either ground or top coats that are inert enough to permit the full development of suitable crystalline effects. For this type of finishing, the metal surfaces must be clean and smooth, and the finishing must be performed in a room which is free from dust and air currents and which is preferably around 85°F in temperature.

Crackle Finish. "Crackle" finish is a multiple-coat finish obtained with two coats of lacquer and one coat of crackle. It results in a variety of attractive effects, ranging from a close resemblance to alligator leather to a fine, cracked texture.

Crackle is usually an overpigmented material which, when dried over a lacquer undercoat, pulls apart and shows the undercoat as lines separating the areas of the crackle. A thin coat of crackle results in fine lines and small areas; a heavy coat results in large irregular areas separated

by heavy lines. To get uniform results, careful spraying and rigid control of the concentration and viscosity of the lacquer are required. The undercoat, which also serves as a primer, can be of any color. Since the layer of crackle is somewhat loosely attached to the undercoat and can be easily rubbed off, the usual practice is to apply a coat of clear lacquer, gloss or flat, as a finish coat. Colored finish-lacquer coats can also be used; this procedure gives a one-color effect instead of the contrasted colors of the previous system, but results in a finish that is much more resistant to scuffing and impact.

Veiling and Webbing Lacquers. These finishes are occasionally used for decorative effects. In applying them, advantage is taken of the property of solutions of rubber and certain synthetics to emerge from a spray gun in cobwebby threads. When these colored threads are sprayed skillfully over a suitable ground coat, an attractive effect is obtained. High operator skill is necessary, however, and since these lacquers are sprayed at high viscosity, a special nozzle is needed for the spray gun. Among the applications for this type of finish are die castings for vending machines and advertising novelties.

Hammered Effects. Hammered or dimpled effects form another type of novelty finish. The base is quick-drying synthetic enamel containing a small percentage of a special bronze powder. As soon as this coating has been applied, more of it is mixed with a volatile solvent in a special nozzle and is sprayed on at low pressures. This mixture strikes the surface as individual drops and dries quickly, leaving the appearance of a hammered metal surface. The finish may be baked if desired, or it may be formulated to dry in air.

Pearl Essence or Opalescent Finish. Pearl or nacreous effects are invariably obtained with an opalescent ingredient mixed with lacquer. The active ingredient is pearl essence, which is laboriously removed from the scales of certain fish. The next step in this process is to mix these crystals in a lacquer paste that mixes freely with other lacquer. By mixing the pearl essence with enamels, pearly effects are obtained. A mixture of pearl essence and black lacquer produces a beautiful gun-metal or black pearly surface that is especially effective when applied on polished metals.

The potential value of this, and of the other novelty finishes, is not exclusively as an over-all finish for a given article; it can also be used to accentuate conventional finishes by application to comparatively small areas. Properly compounded and applied, the choice of wrinkle or crackle, crystal or cobweb, or pearl or hammered finishes adds novelty and beauty to zinc, aluminum, and magnesium die castings.

In addition to the finishes just described, there are others that can be used to obtain speckled, spattered, or marbleized effects.

Flock Finishes for Zinc. Flock finishes are produced by applying finely cut particles of synthetic vegetable or animal fibers over suitably prepared metal surfaces. The flock may be blown on a surface which is coated with an adhesive, or else suspended in a suitable carrier and sprayed on. Effects such as suede, velour, velvet, felt, mohair, carpet, and fur can be obtained in any color, using rayon, nylon, cotton, wool, and hair fibers.

Dyed and treated rayon flock has the rich beauty of plush velvet or velour; this type of flock is adapted to a wide variety of uses because it dyes to deep rich colors, produces a great depth of pile, and has effective acoustical properties. Cotton flock produces a coating having the characteristics of suede which is highly successful when a suede-leather or felt effect is desired; it produces a cushionlike surface. Wool flock gives a soft dull finish and is used effectively in black for the interiors of cameras and for other articles on which a deep, nonreflecting black is needed. Animal-fiber flock produces surfaces simulating carpet or floor-mat materials.

This type of finish has many possible uses. Its properties of sound deadening, shock absorbing, insulating, and surface marproofing are especially effective when used to finish gift boxes, jewelry cases, packaging parts, book ends, and display signs. It also can be applied to ash trays, lamps, record turntables, telephone bases, and other parts that must have nonmarring surfaces.

FINISHES FOR ALUMINUM-BASE ALLOYS

On exposure to air, aluminum and its alloys are covered with a thin, transparent film of oxide that protects the surface against corrosive attack. For numerous applications, the ability of aluminum alloys to form and hold this natural oxide film is sufficient protection, and further finishing for protection is not required. It is only when this thin film is broken or removed under some service condition or under certain corrosive conditions that a protective finishing treatment is warranted.

Mechanical Finishes for Aluminum. Mechanical finishes are used much more extensively for decorative purposes on aluminum die casting than on castings made of other alloys (Fig. 8.12). They also are used, of course, to prepare a casting for subsequent plating, painting, or chemical treatment.

When mechanical finishes are an end in themselves, they serve only a decorative purpose, since they have no substantial effect on abrasion or

corrosion resistance. They do, however, maintain the characteristic resistance of aluminum die castings to ordinary indoor exposures and, in general, simplify cleaning and polishing.

Some aluminum alloys possess better surface corrosion resistance than others. For instance, the higher purity aluminum alloys, or those having low copper or nickel contents, keep their polished luster for longer periods of time than those alloys having relatively high contents of these metals. Some alloys also possess greater color and surface reflectivity in the polished condition than do others. Polished aluminum alloys having a high-silicon content are duller and darker than polished pure aluminum or polished alloys that are low in silicon. The binary magnesium-aluminum-type alloys are capable of being polished to a brighter and whiter finish than other aluminum alloys and hold their polished luster for longer periods of time. When it is necessary to consider such factors as the "color" or "life" of a polished aluminum part, therefore, the type of aluminum alloy to be used becomes important.

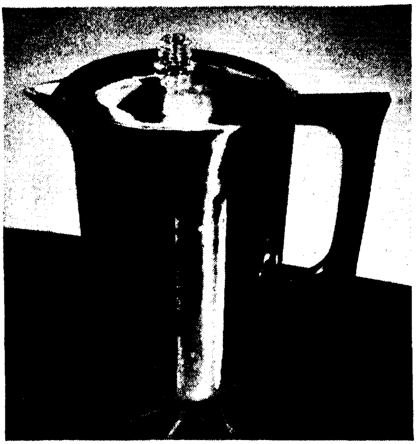

FIG. 8.12. Mechanically finished die-cast aluminum coffeepot.

Polishing. The sequence of operations generally referred to as *polishing* may begin with *roughening* (Fig. 8.13). This is accomplished with a wheel of glued rag construction, having a working surface of relatively coarse emery particles—80 to 120 mesh—embedded in glue. Wheel diameters range from 6 to 16 in. and wheel thicknesses from 1½ to 3 in. Speeds of about 6,000 fpm are suitable for most work. The use of tallow or a composition lubricant will avoid excessive heating and thus will prevent breakdown of the glue binder.

Oiling. Oiling is a refinement of the roughening procedure, with finer abrasives and softer wheels. For the average die casting, on which flow marks and other surface defects are not too deep, oiling may be the initial step in polishing. The wheels are of solid felt construction and are faced with emery of 120 to 200 mesh. Wheel speeds, dimensions, and lubricants are approximately the same as for roughing. Selection of a felt of suitable hardness is important to obtain the proper work pressure without removing an excessive amount of metal from the surfaces. Small, irregular castings require softer wheels than flat, extended sections.

For buffing, wheels are built up from a series of stitched rag buffs, hardness being controlled by the extent and manner of stitching. The abrasive and lubricant are in the form of a cake—usually tripoli powder in a grease binder—that is periodically applied to the wheel surface. Buffing-wheel speeds range from 7,000 to 7,500 sfpm. Satisfactory results depend upon a proper balance of wheel hardness, abrasive compound, wheel speed, and work pressure.

FIG. 8.13. Polishing the inside diameter of the coffeepot shown in Fig. 8.12.

Coloring. Coloring is a modified buffing operation that produces a surface of high gloss (Fig. 8.14); it may be used either as a final finish or as the foundation for other finishes. Before this operation, it is advisable to remove all abrasive material from the castings either by solvent cleaning or, when abrasive particles have become embedded in the surface, by a light caustic etch. Open muslin or flannel wheels, to which soft silica or lime is applied as an abrasive, are used. Wheel speeds should equal or slightly exceed those for buffing: 7,500 to 8,000 sfpm.

Scratch Brushing. A textured effect of attractive appearance can be achieved by scratch brushing. This is done on the as-cast surface following cleaning or a light acid etching operation. Wheels are made of stainless steel, brass, or nickel-silver wire and are about 10 in. in diameter. Wire size ranges from 0.010 in. up, depending upon the coarseness of

texture sought. Wheel speed should be about 2,000 rpm. Metallic particles should be periodically removed from the wire wheel with a soft brick, and periodic reversal of the direction of rotation is necessary to maintain the cutting action of the wires. After being scratch-brushed, the castings often are dipped in an acid bath to remove embedded metal particles coming from the brush.

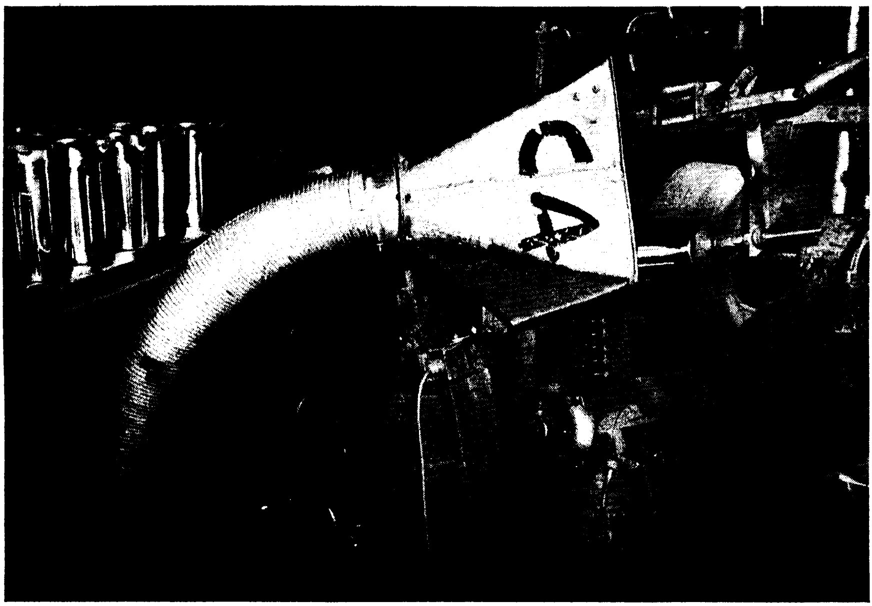

FIG. 8.14. Coloring, the final operation on many aluminum parts that are finished mechanically, puts a high gloss on the surface.

Satin Finishing. If a smaller and softer wire wheel is used than in scratch brushing—0.002- to 0.005-in.-diameter wire—a satin finish is obtained. This finish differs from a scratch-brushed finish in that finer lines of less depth are produced on the surface. Therefore, an initial oiling treatment may be necessary to remove surface defects that might otherwise be visible after finishing. Wheel speeds for satin finishing range from 450 to 600 rpm.

A similar effect can be obtained if an operation involving the use of greaseless satin-finishing compounds is substituted for the buffing operation. In this case, the abrasive action produces fine parallel lines similar to those obtained by fine wire brushing.

Tumbling or Burnishing. Barrel burnishing is well adapted to the low-cost handling of parts in quantity and is a popular method of

finishing small aluminum die casting. The castings are tumbled, in batch lots, in wood-lined barrels. As a result of the peening action of the steel balls, stars, or other abrasive materials, a bright finish is produced. Barrel speeds range from 15 to 35 rpm, and burnishing times from 30 to 60 min. Ordinarily, the barrel is filled about half full with peening materials and castings, in a ratio of about 2:1. Clean water, to which is added a few ounces of neutral soap flakes, brings the

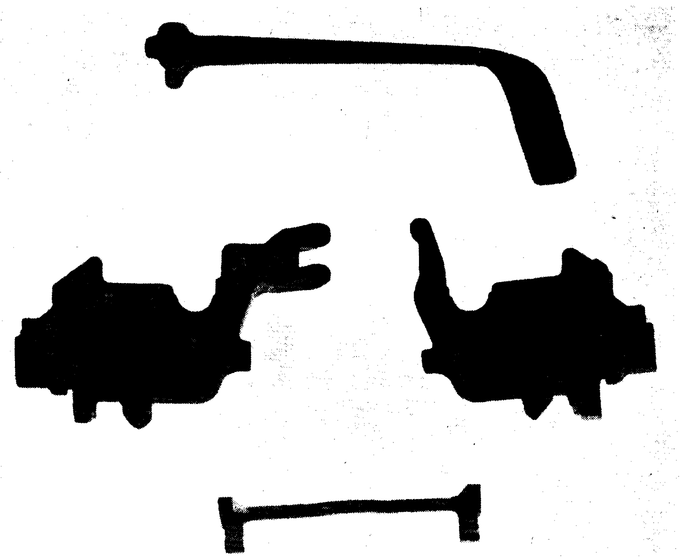

FIG. 8.15. Sand-blasted die castings. Sand blasting results in a matte finish on the part.

barrel level to about two-thirds full. It is important that parts be cleaned before burnishing, or else given a light acid etch and a water rinse. Following burnishing, the castings should be rinsed in clean, hot water and dried in sawdust.

Sand Blasting. Sand blasting is a rapid method for obtaining uniform matte finish on the surface (Fig. 8.15). The texture and color of the sand-blasted surface are determined by the grade of sand or abrasive employed, the rate of introduction of the sand, the air pressure, and the nozzle-to-work distance and angle. The conditions selected must be strictly adhered to if a uniform surface is to be obtained from casting to casting.

Fine sand (dust blasting) is sometimes employed, particularly for castings that are to be anodically coated. Treatment with hot caustic-

soda solution after blasting may be necessary to remove embedded abrasive particles from such parts. This etching treatment also results in a lighter color in the finished oxide coating.

Interesting two-tone effects can be secured by combinations of polishing, buffing, and sand blasting.

Vapor Blasting. Vapor blasting is somewhat similar to sand blasting, but instead of sand, a mixture of water and finely divided abrasives is used, the abrasive ranging from 325 to 1,200 mesh. The wet abrasive is forced against the article under a pressure of about 60 psi. Although this process does not remove any appreciable amount of stock from the surface of a part, it does remove oil, dirt, oxide films, and other extraneous matter and results in a uniform, mattelike, satin finish.

Hammering. As the name implies, hammering is a treatment that is used to obtain an irregular pattern of depressions on the surface of a part. It simulates the effect obtained by ball peening and produces an appearance somewhat like that of antique hand-hammered metals.

Electroplated Finishes for Aluminum. Aluminum and its alloys, because of their ability to take and hold a polished luster for long periods of time, usually are not electroplated. It is only in special cases, such as when the need to match other parts arises or for severe corrosion resistance, that aluminum requires to be electroplated (Fig. 8.16).

Another objective in electroplating aluminum might be a change in color or appearance. However, resistance to abrasion or wear can be increased by a suitable electrodeposit, and any tendency toward smudging can be eliminated. Other objectives are to improve electrical contacts, to facilitate soft-solder joining, and to permit direct rubber bonding.

The difficulty is that aluminum does not respond satisfactorily to ordinary electroplating techniques. The lack of adherence of some electroplates on an aluminum surface has been attributed to a variety of reasons, such as the presence of the natural aluminum-oxide surface film. Over the past few years, a number of methods have been advanced to overcome this difficulty. Some of these methods have merit, while others have proved to be impractical.

At the present, there are two generally accepted processes, (1) the phosphoric acid, anodic-plating process, and (2) the zinc-immersion process.

Only the zinc-immersion process will be described because the phosphoric acid, anodic process does not readily lend itself to the plating of die castings, and the zinc-immersion process appears to be the most adaptable of the various plating procedures studied. It most nearly

approaches a universal pretreatment and is definitely less critical than the anodic process.

The Zinc-immersion Process. Some of the earlier methods for plating aluminum were based in part upon the fact that aluminum is less noble than many of the common metals, and the acid plating solutions of iron, manganese, and nickel depended upon this property. In these solutions,

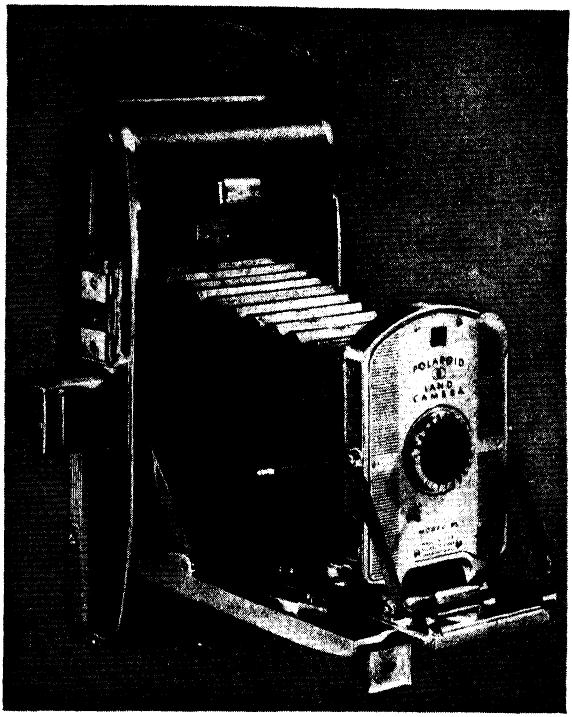

FIG. 8.16. Electroplated aluminum parts for still camera.

metal replacement was accompanied by considerable surface etching, and the adherence of the electroplate depended upon a keying action between the immersion layer and the base metal.

The zinc-immersion process differs from these methods in that a strongly alkaline solution is used: a solution of sodium zincate in caustic soda. When aluminum is immersed in this solution, an adherent and continuous deposit of zinc is formed. The reaction might be considered self-arresting, for as zinc is deposited on the surface, the reaction slows down and finally stops, thus preventing any objectionable roughening of the surface. The temperature of the zinc-immersion solution should

be approximately room temperature, *i.e.*, about 80°F. Either the work or the solution should be mildly agitated.

The solution is very viscous and losses entailed are largely from "drag-out." This drag-out is considered advantageous, for it limits the accumulation of impurities resulting from attack upon the aluminum. There is sometimes evidence of dilution, probably due to water carried in by the work, and also due to hygroscopicity. Loss of volume caused by drag-out should be corrected by the addition of more solution of the specified composition, and the specific gravity of the solution should be periodically checked and adjusted.

Also, the presence of copper compounds is detrimental to the zincate bath; therefore, the copper content of the bath should be no greater than that resulting from copper impurities introduced by the commercial grades of zinc oxide. Copper contamination resulting from copper-bearing aluminum alloys does not reach an objectionable amount.

After the zinc-immersion treatment, plating methods that are ordinarily used for zinc-base alloys can be applied for electroplating the zinc-coated aluminum. The zinc-immersion layer is very thin, however, and plating treatment that penetrates this layer and attacks the aluminum base metal may result in a poor deposit. If such attack is likely to occur, common practice is first to apply a strike deposit in a rochelle-type copper cyanide solution; electrical contact is made quickly, and an initial high current of 24 amp/sq ft is used to effect rapid coverage. After a 2-min deposit at this current density, the current is reduced to 12 amp/sq ft and the deposition is continued for 3 min or more. The work can then be transformed to the finish plating bath.

Finishing plates of nickel, brass, silver, chromium, or other metals can be deposited on zinc-coated aluminum, as follows:

Nickel. Nickel may be applied after depositing a copper strike in a rochelle copper solution or may be deposited over the zinc immersion surface if a nickel bath specifically designed for plating directly on zinc is used.

Brass. Brass may be applied directly from a standard plating solution operated at room temperature. For aluminum alloys containing appreciable magnesium, a brass deposit is used as a strike prior to copper or nickel plating.

Silver. Silver may be deposited on the zinc-immersion surface by following the usual procedure for silver plating.

Chromium. Chromium may be applied over the immersion zinc layer if first deposited from a solution at 65 to 70°F. After a preliminary deposit is applied at this low temperature, plating can be continued at high temperatures (130°F) to obtain heavy and hard deposits.

A summation of the recommended procedure for plating aluminum-base alloys is given in Tables 8.4 and 8.5. The quality of adhesion developed for electroplates by these procedures is surprising. The bond strength is generally greater than the cohesive strength of the base metal. When a heavy electroplate is torn off a casting, rupture takes place in the base metal. This indicates that the bond is interatomic rather than mechanical.

TABLE 8.4. RECOMMENDED SEQUENCE OF OPERATIONS FOR PLATING ALUMINUM-BASE ALLOYS

Operation		Composition of solutions		Bath temperature	Immersion time	Container
No.	Type	Material	Amount			
1	*a.* Vapor degrease or mineral spirits *b.* Inhibitive-alkaline dip	Caustic soda	6.7 oz/gal	150°F	10 sec	Steel
2	Acid pickle	Chromic-sulfuric acids		Room	3 to 5 sec	
3	Water rinse					
4	Mixed-acid dip	Conc nitric acid Hydrofluoric acid (48 per cent conc)	3 parts 1 part	Room	3 to 5 sec	Steel lined with carbon brick (National Carbon Company specifications)
5	Water rinse					
6	Acid pickle	Chromic acid Sulfuric acid	4.7 oz/gal 24 oz/gal	150°F	1 to 5 min	Steel lined with carbon brick or lead
7	Water rinse					
8	Zinc immersion	Zinc oxide Caustic soda	13.4 oz/gal 70.4 oz/gal	Room	2 to 5 min	Steel
9	Double water rinse					
10	Copper strike in Rochelle copper bath	Copper cyanide Total sodium cyanide Sodium carbonate Rochelle salts Free sodium cyanide	5.5 oz/gal 6.8 oz/gal 4.0 oz/gal 8.0 oz/gal 0.75 oz/gal			
11	Water rinse					
12	Electroplate					

Of course, as with all electroplated finishes, the effectiveness of the bond between the plate and the aluminum is determined to a large extent by the methods that are used to clean and rack the castings and by the

care that is exercised during these operations. No difficulty is encountered, however, if the following recommendations are put into effect.

Cleaning. The cleaning method that is selected will depend upon the condition of the metal. If much oil or grease is present, vapor degreasing or solvent cleaning is necessary. The nature of the method selected will determine whether an alkaline cleaning treatment is desirable. If used, the alkaline cleaner should be inhibited so as not to attack aluminum.

TABLE 8.5. COMPOSITION OF SOLUTIONS USED IN PLATING ALUMINUM

Solution	Composition	Time	Temperature	Container	Exhaust fumes
Nitric acid	Conc commercial nitric acid	10 to 15 sec	Room	Steel lined with 18-8 Columbian-bearing, stainless steel exhaust system	No
Mixed-acid dic	3 parts conc commercial nitric acid plus 1 part commercial hydrofluoric (48 per cent) acid	3 to 5 sec	Room	Steel lined with carbon brick (National Carbon Company specifications)	Yes
Acid pickle	Chromic acid: 4.7 oz/gal Sulfuric acid: 24 oz/gal	1 to 5 min	150°F	Steel lined with carbon brick or lead	Yes
Zinc-immersion treatment	Zinc oxide: 13.4 oz/gal Caustic soda: 70.4 oz/gal	2 to 5 min	Room	Steel	No
Caustic dip	Caustic soda: 6.7 oz/gal	10 sec	150°F	Steel	Yes
Rochelle copper bath	Copper cyanide: 5.5 oz/gal Total sodium cyanide: 6.8 oz/gal Sodium carbonate: 4.0 oz/gal Rochelle salts: 8.0 oz/gal Free sodium cyanide: 0.75 oz/gal				

After the superficial surface dirt has been removed, parts to be plated are given an acid etch which removes a thin layer of metal together with embedded impurities. For die castings, particularly of the high-silicon type, this is usually done in a mixed-acid dip, although it sometimes is necessary to use a combination of acid pickles to obtain satisfactory results.

Racking. Aluminum racks are preferred, since some of the solutions attack copper or copper-alloy racks. It has also been found that if aluminum is in contact with copper, the unlike metals produce an electrolytic effect in the zinc-immersion solution; this electrolytic action interferes with the character of the deposited zinc film and makes it subject to localized blistering during the subsequent plating operation. In addition, the general recommendations for racking, discussed previously under the section on electroplating zinc die castings, should be observed.

Chemical Finishes for Aluminum. Besides the zinc immersion treatment, described in the previous section on electroplating, there are other

chemical immersion treatments that are suitable for aluminum die castings. Most of these treatments are based on the high chemical activity of aluminum, *i.e.*, its tendency to oxidize and form a protective surface oxide coating, or on its ability to displace less active metals from solution, thus forming a chemical coating of the displaced metal on the surface.

Alrok Coatings. Aluminum die casting can be oxide-coated by chemical treatments known as the *Alrok processes.* One of these, which is commonly employed, is an immersion treatment in a hot solution of sodium carbonate and dichromate. A substantial oxide coating forms

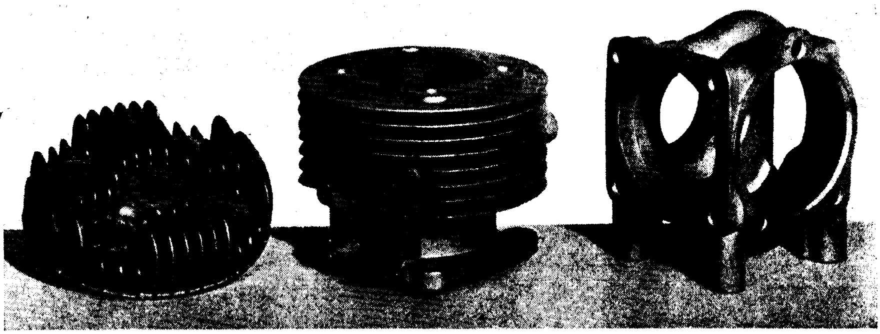

FIG. 8.17. Compressor cylinder head, cylinder, and crankcase that were given a Bonderite finish prior to painting to improve the adherence of the coating.

after an immersion period of about 15 min. This oxide coating increases the abrasion resistance of the surface, but is less effective in this respect than a good anodic coating. The protection it affords in corrosive environments can be further improved by sealing the casting after treatment in a hot dichromate solution. If the castings are to be subjected to severe service conditions, it is frequently desirable to apply such a chromate-sealed oxide coating prior to painting or enameling.

Bonderite 170. This is a chemical treatment patented by the Parker Rust Proof Company for producing a phosphate film on the surfaces of aluminum by immersion (Fig. 8.17). The protective film inhibits corrosion and acts as a base for and increases the adherence of subsequent oxide finishes.

Bauer-Vogel Treatment. This is another chemical immersion treatment used to produce a protective oxide film on aluminum alloys that are relatively free of copper. It involves the immersion of aluminum parts in an aqueous solution containing about 5 per cent sodium carbonate and about 1.5 per cent sodium chromate. The temperature of the

bath is held at about 200°F, and the immersion period is about 5 min. The film that is produced is slate gray in color and is useful as a base for paint finishes.

Jirotka Process. In this treatment, an aluminum oxide film is obtained by immersing the casting in a solution containing salts of heavy metals—copper, zinc, nickel, cobalt, or chromium—which are deposited in metallic form on the aluminum oxide film. These coatings have good adhesion and are useful as bases for subsequent paint coatings.

As one illustration of this treatment, the bath can be made up of about 5 per cent alkali permanganate; 2 per cent hydrofluoric, sulfuric, or acetic acid; 5 per cent sodium chromate; and 0.5 per cent heavy metal salt. A mixture of about 1.2 per cent hydrogen peroxide and 2 per cent sodium dichromate may be substituted for the acid. This bath is operated cold, and the work is immersed in it for from 20 to 60 min.

Caustic Etch. Aluminum die castings can be frosted and etched by treating them in a hot solution of caustic soda. The solution should contain about 15 per cent sodium hydroxide and should be maintained at a temperature of 160 to 180°F. The time of etching will depend upon the effect desired and on the concentration and temperature of the solution. After etching, the casting is rinsed in clear, cold water and then given a neutralizing and brightening treatment by dipping it in a strong mixture of nitric and hydrofluoric acids. This mixture is composed of from three to eight parts of concentrated nitric acid and one part of concentrated hydrofluoric acid. Hydrofluoric acid is essential if the alloy contains silicon in substantial amounts. The acid mixture should be used cold; if it becomes too warm during use, it produces a yellow film that is difficult to remove. After this treatment the casting is again rinsed in clear, cold water and then dried on a steam table.

Electrolytic Oxide Coatings for Aluminum. Anodic oxide coatings are substantially thicker and more abrasion resistant than a natural oxide film. Furthermore, some anodic coatings are highly resistant to attacks, while others may be used only for their decorative effect either without further treatment or by impregnating them with dyes or mineral pigments.

The method of applying these coatings is simple and can be closely controlled. The article to be coated first is given the necessary polish or texture; it is then made the anode in a suitable electrolyte which, in the commonly used Alumilite process,* is dilute sulfuric acid. When using this electrolyte, the time required for coating ranges from about 10 min to 1 hr. Methods employing other electrolytes, such as chromic

* Patented process of the Aluminum Company of America.

acid, oxalic acid, phosphoric acid, sulfamic acid, and boric acid, may also be used. In most cases, the thickness of the coatings is between 0.0001 and 0.0005 in.

On pure aluminum, the oxide coating is transparent or substantially colorless, but the color and appearance may be profoundly modified by the alloying elements that are always present in die-casting alloys. These elements may also affect the hardness, porosity, and protective value of the oxide coating. Depending upon their electrolytic behavior, alloying constituents may dissolve during the coating operation, may oxidize and remain in the coating, or may remain in the coating in the unoxidized state.

For example, silicon is not appreciably dissolved or oxidized during the oxidizing treatment and remains in the coating. Therefore, die castings with a substantial silicon content are usually gray to black in appearance after being anodically oxidized. Iron also tends to discolor the oxide coating and should be kept at a minimum when light-colored, uniform coatings are desired. Copper constituents, such as $CuAl_2$, have quite the opposite behavior; these constituents are anodically oxidized and dissolved at a more rapid rate than the aluminum matrix. As a result, the coating formed on an alloy that contains substantial amounts of copper is porous and has low abrasion and corrosion resistance. Alloys containing substantial amounts of undissolved magnesium constituents have a dark appearance when anodically coated.

In so far as color is concerned, alloying elements in the solid solution have the least effect. Heat-treatment of the die casting will affect the amount and degree of dispersion of the partially soluble elements and hence may have an important effect on the color of the oxidized casting. The oxide coating on a heat-treated casting is usually lighter in color than on an untreated casting.

Thus, in selecting the alloy best adapted for anodic treatment, certain generalizations should be kept in mind. Anodic coatings on alloys containing 4 to 8 per cent magnesium are hard, abrasion resistant, light in color, and attractive in appearance. An alloy of 2 per cent copper plus 2 per cent nickel has a good appearance after anodic coating. When a dark color is desired, or at least not objectionable, ASTM alloys S4 or S9 containing 5 per cent and 12 per cent silicon, respectively, may be used; the substantial silicon content of these alloys gives them a dark color after anodic coating.

Because of the effect of alloying constituent on the appearance of the coating, any lack of microscopic homogeneity in the surface structure of the casting may result in a nonuniform, mottled appearance. Anodically coated die castings may also show flow lines which are caused by slight

variations in the rate of chill on various parts of the surface; a fine sand or vapor blast makes them less prominent. In fact, the surface preparation employed prior to anodic coating is an important factor in producing an attractive finish.

If, in addition to appearance, the thickness or the corrosion or abrasion resistance of the coating are of considerable importance in a particular

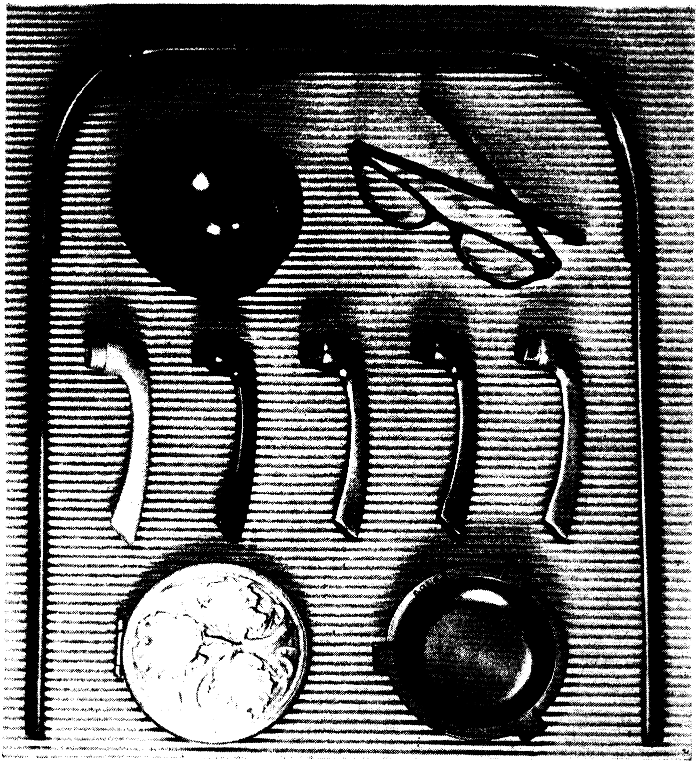

FIG. 8.18. Colored anodic coatings on aluminum parts.

application, a positive test should be employed to determine these qualities. The measurement of the electrical breakdown voltage of the coating yields useful information as to thickness and porosity. The weight of coating per unit area can usually be closely correlated with thickness. Abrasion resistance can be measured by the abrasive air-blast method. Salt-spray tests are usually employed for evaluating the protection against corrosion offered by the coating.

A coating can be given added protection, particularly against salt-containing atmospheres, by sealing in a chromate solution so that the

coating retains within its pores substantial amounts of chromate inhibitor. Coatings sealed in this way usually have a green to yellow color. Other sealing methods are available where coloration is objectionable.

Colored Anodic Oxide Coatings. If anodic coatings are to be colored, they can be purposely made porous so that they will more readily absorb dyes; such coatings can also be impregnated with mineral pigments by precipitating the pigment within their pores.

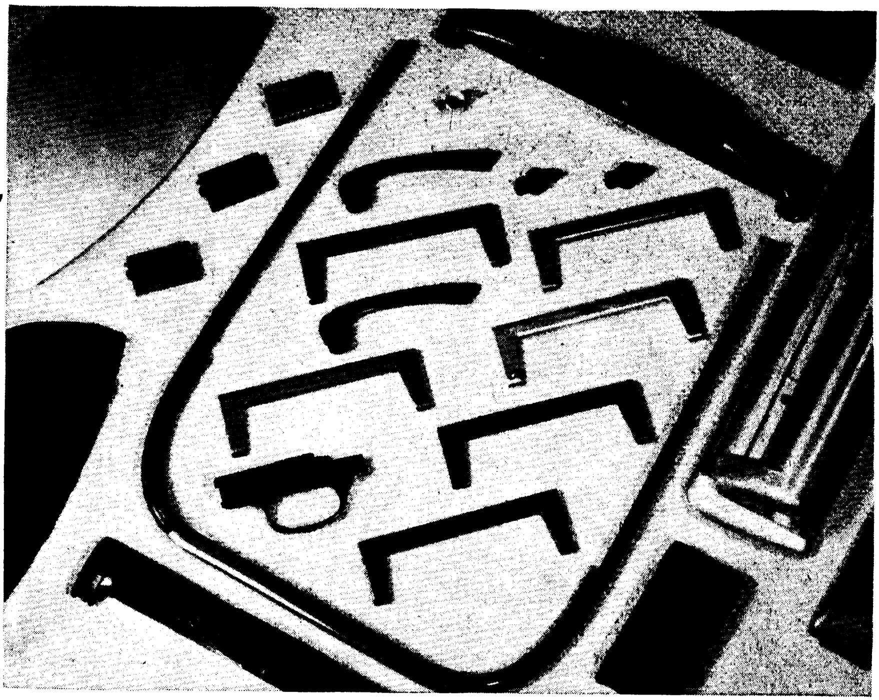

FIG. 8.19. Anodized coatings on aluminum die castings.

To produce a colored anodic coating with a high luster, such as shown in Figs. 8.18 and 8.19, a smooth, mirrorlike finish must be given the casting by buffing. All traces of grease and buffing compound must be removed from the surface with an organic solvent or vapor degreaser. Since most of these solvents attack the insulating material used to block off the racks, the castings must be degreased in baskets before racking. The castings can then be fastened on suitable racks, rubber gloves being used to prevent grease on the hands from contaminating the surfaces.

The racks must make firm electrical contact with the castings throughout the operation. Should the contact between the rack and the casting

be broken, even momentarily, an anodic film will form between them, causing poor electrical contact and thus an inferior coating and a variation in the color intensity when the coating is dyed.

Any portion of the rack that is exposed to the electrolyte must be made of aluminum or an aluminum alloy that will form an anodic coating; this alloy should have an electrical resistance as great as or greater than the article being treated, for otherwise current loss through the rack will cause inferior and nonuniform coatings on the articles being treated. Enough current must be supplied to form an oxide coating on the rack as well as on the casting. This coating must be removed from that portion of the rack making contact with the casting before it is reused; this can be done mechanically or by stripping the coating in a caustic soda solution. If a considerable portion of the rack is exposed to the electrolyte, it should be coated with an insulating material.

In the normal sequence of operations, the rack and castings are submerged in a 15 per cent solution of caustic soda that is agitated and held at room temperature. After an interval of 10 to 15 sec, the rack and castings are removed, rinsed in cold water, and dipped in concentrated nitric acid. The work is lifted and submerged several times in the nitric acid and then given a thorough rinse in cold water to prevent any contamination of the anodizing tank into which they are next placed.

The tank containing the electrolyte is lined with either lead or rubber. The electrolyte is a solution of sulfuric acid, the temperature of which must be controlled within 5°F. A small variation in temperature or concentration of the electrolyte causes a difference in coating density and thickness and therefore a change in color intensity when dyed. The most common method of controlling temperature is to mount lead cooling coils on the inside walls of the tank. In the event that the room temperature should drop much below the bath temperature, hot water or steam can be passed through these coils to heat the solution.

Considerable heat is generated during the coating process due to the reaction that takes place on the surfaces of the parts being oxidized. Therefore it is necessary that the electrolyte circulate rapidly over the articles to prevent overheating, because should the surfaces be overheated, the oxide would dissolve as rapidly as it is formed. To provide the necessary circulation, either air or mechanical agitation is employed.

The articles to be coated are suspended by the racks in the electrolyte and made the anode. If the tank is lead lined, it can serve as the cathode; but if the tank is rubber lined, lead cathodes with an area as great as or greater than that of the anode (casting area plus exposed rack area) must be placed in the tank. These cathodes must be equally distributed around the tank.

The most troublesome factor in anodizing die castings for decorative purposes is the formation of dark streaks in the oxide coating. Black and dark-blue dyes will obscure this structure, but red, yellow, gold, green, and all pastel dyes will not. By the use of a low current density during anodizing, this formation can usually be minimized or eliminated. For producing an anodic coating suitable for pastel shades, a current density of 5 amp/sq ft with a resultant voltage drop across the electrodes of 4 to 6 volts, depending upon the alloy, has given very satisfactory results when used in an electrolyte of 24 per cent by weight (or 15 per cent by volume) sulfuric acid; the bath is held at 70°F (±1.0°F), and the castings are treated for a period of 10 min.

A coating for the deeper shades can be produced under the same conditions by extending the anodizing time to from 20 to 30 min. For some alloys, a current density of 8 to 10 amp/sq ft for periods of 10 to 20 min can be used without causing objectionable structures. This cycle is sometimes necessary to produce coatings capable of absorbing sufficient dye materials to produce deep shades of red and green. An anodic coating suitable for taking black dye can be produced with a current density of 15 to 18 amp/sq ft for a period of 40 min.

When the anodic treatment is completed, the racks and castings are removed until the final dyeing and sealing operation; care must be taken that they are not touched by unprotected hands or in any way come in contact with traces of oil or grease. The slightest amount of grease will render the coating incapable of absorbing any dye. Should it become necessary to handle a casting at this point, it can be done by using a pair of clean, wet rubber gloves.

The castings are then rinsed alternately in nitric acid and running cold water several times before dyeing. This procedure helps greatly in preventing white spots ("bleed-outs") around pinhole openings in the coating—a condition that is caused by sulfates which remain in the pores and bleed out in the hot dye solution. After a final cold-water rinse, the castings are ready to be dyed.

The tanks containing the dye solution should be constructed of Monel and should be of sufficient size to receive the complete rack with castings without danger of it touching the sides. Some means must be provided to maintain a temperature of 140 to 160°F. If steam coils are used for this purpose, they too must be constructed of Monel. Agitation of the dye solution is necessary and can best be accomplished by mechanically driven agitators at the bottom of the tank; however, constant motion of the rack and castings during the dyeing period will suffice. A concentration of 3 to 5 g of dye per l of water is ample for all shades except black, in which case a concentration of 15 g/l of water is desir-

able. The castings are submerged for a period of from ½ to 10 min, depending upon the intensity of color desired. After dyeing, they are given a cold-water rinse and placed in a 5 per cent solution of nickel acetate held at 200 to 212°F for 5 min to seal.

The nickel acetate tank should be constructed of either copper or Monel. Following the sealing operation, the castings are given a cold-water rinse and dried. The sealing operation may leave a powdery film on the surface. This can be removed by drying the castings with a soft cloth; however, if they are placed in hot water and air-dried, a light-color buff may be necessary to restore the original luster.

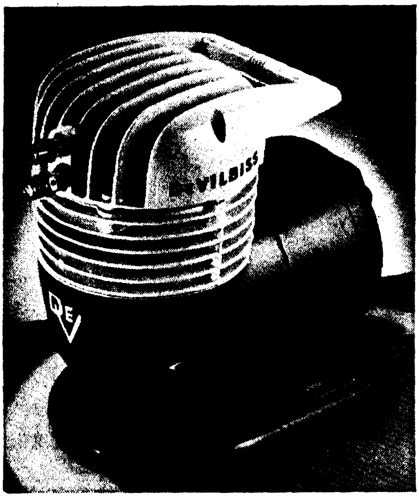

FIG. 8.20. The striking appearance of this painted compressor attests to the decorative appeal that can be obtained with organic coatings.

Organic Finishes for Aluminum. Aluminum die castings may be coated with paint or lacquer, either for decoration or for protection against a severely corrosive environment. When decoration is the principal objective (Fig. 8.20), the preparation of the surface is not usually so important a step in satisfactory paint performance as when protection is the primary requirement. Good abrasion resistance is often desired, however, and hence adequate anchoring of the paint is important.

The surfaces of aluminum die castings may be prepared for painting in a number of ways. Solvent cleaning is perhaps the simplest form of surface treatment, and for many applications this may be sufficient. The most effective method of solvent cleaning is that of solvent vapor degreasing. A light roughening of the surface, as by sanding, improves the wearing qualities of the finish.

A still more effective method of surface preparation is chemical treatment with a dilute aqueous solution of phosphoric acid. These solutions are more effective if organic solvents are added. The solvents aid in grease removal and permit ready action of the phosphoric acid, which apparently forms a thin film of protective aluminum phosphate on the surface. A number of proprietary treatments of this type are available.

Alrok coatings provide an excellent base for the application of paint and are especially recommended where service conditions are severe, such

as in atmospheres of high humidity. Anodic coatings may also be used under these conditions and in some instances may prove even better. The Alumilite finishes provide corrosion-resistant, adherent, impervious oxide films that constitute ideal bases for paint.

Following the surface treatment, the castings are thoroughly dried before paint is applied. They should be heated to a temperature above the boiling point of water for about 30 to 60 min to ensure complete removal of water on the surface and should receive a minimum amount of handling prior to painting.

Either dipping or spraying can be used to paint die castings. The method of application to be employed is determined by existing manufacturing facilities and by design of the casting; some shapes do not lend themselves readily to a dipping operation.

As in the case of other base metals, the use of a suitable priming coat on aluminum is necessary to obtain maximum serviceability from the finish. In addition to good adhesion, the primer should have good resistance to moisture penetration to prevent surface reaction and should contain a corrosion-inhibitive pigment. Zinc chromate has among the best corrosion-inhibitive properties of any of the pigments that have been tested. Primers of this type are usually made with synthetic resin vehicles, which improve their resistance to penetration by moisture. Primers containing lead pigments should not be used on aluminum die castings.

Aluminum paint is a satisfactory primer under most conditions and often is used as a finish coat; it possesses high impermeability to moisture and has good adhesion characteristics.

Often it is desirable to employ baked coatings, in which case the vehicle employed for the primer should be one which will withstand baking at a moderate temperature for at least 1 hr, since baked finishes should be applied over baked primers. Properly formulated synthetic resin varnish vehicles of the phenolic or alkyd types have been found to be quite satisfactory for this purpose. When pyroxylin lacquer systems are used in finishing the die castings, special primers must be employed, since many types of primers are "lifted" by the powerful solvents used in lacquer formulation.

With the exception of special lacquers, almost any durable paint or enamel may be used for the finishing coat. Synthetic resin enamels are particularly effective, since they can be formulated to give hard, durable finishes that are highly resistant to moisture penetration. When speed of drying is a controlling factor, lacquer finishes are recommended. Durable lacquer enamels may be secured in any desired color, but special primers must be used with them.

Another type of finishing process frequently employed for aluminum die castings is *black japanning*. A single coat is often sufficient, but if greater durability is desired, multiple coats are used. Japan coatings are baked at a relatively high temperature (usually in excess of 400°F) and form hard, abrasion-resistant films that have good resistance to penetration by moisture and solvents. Similar coatings may be produced in a variety of colors with heat-reactive phenolic resins.

If it is desirable to preserve the natural color and appearance of the aluminum, clear lacquers or synthetic resins can be used. Methacrylate resins or resins containing cellulose esters such as cellulose acetobutyrate are especially suitable for this purpose. Clear varnishes made with alkyd or urea formaldehyde resins, or a combination thereof, form very satisfactory finishes when baked; they are hard and abrasion resistant, and do not turn yellow in service.

Cleaners for Finished Aluminum Castings. There are many different reasons for desiring to clean die-cast parts. After unfinished or mechanically finished aluminum parts have been in service for a period of time, it may be desirable to remove the surface layer of metal to return the casting to its original pleasing appearance. One method of doing this is to dip the casting in a caustic etch. Other surface-renewing treatments include immersion in cold, dilute (1 to 10 per cent) hydrofluoric acid solutions; in cold solutions containing 10 per cent sulfuric acid and 1 per cent sodium fluoride; or in hot solutions containing 10 to 20 per cent phosphoric acid.

Such surface-renewal cleaners should not be used on Alrok- or Alumilite-coated articles, or, as a rule, on complicated built-up structures, since they destroy these coatings and are difficult to remove from crevices or other inaccessible regions. Most liquid or paste waxes and organic solvents, other than chlorinated hydrocarbons, are completely safe cleaners. Soaps or other alkaline detergents are also safe cleaners, provided that they contain a corrosion inhibitor, such as sodium disilicate or sodium chromate, in sufficient amounts.

When rapid or powerful cleaning action is desired, alkaline detergents can be used. The safe operating ranges of such cleaners should be determined by preliminary tests, and they should be employed only within safe limits of concentration. Chlorinated hydrocarbons, such as ethylene dichloride, trichlorethylene, and carbon tetrachloride, are partially safe cleaners; they must be used with care if undesirable attack on the casting is to be avoided.

In many indoor and some outdoor exposures, little cleaning is necessary on bare Alumilite-coated aluminum die castings to maintain a pleasing appearance. Periodic dusting or washing with a safe soap is all that

is required. Periodic applications of liquid wax are also often satisfactory. In more severe exposures, steel wool can be used in applying the wax to remove adherent deposits.

FINISHES FOR MAGNESIUM-BASE ALLOYS

Untreated magnesium gradually acquires a layer of oxide, hydroxide, and/or carbonate when exposed under normal atmospheric conditions. This thin skin on the surface of magnesium parts, once formed and

FIG. 8.21. Magnesium structural member for a baby stroller finished with an organic coating.

not removed, protects the underlying metal from further attack. It is not, however, attractive in appearance and may not provide sufficient protection under severe service conditions; therefore, finishing of magnesium parts becomes a necessity.

For interior applications, magnesium die castings for such equipment as business machines and household appliances are treated with finishes selected for their decorative appeal and wearing qualities (Fig. 8.21). For exterior use, protective finishing is of greater importance. Two or three coats of paint may be satisfactory for normal inland exposures; but for marine and aircraft usage, where exposure is more critical, the best chemical treatment, inhibitive chromate primers, and the maximum protection in finishing coatings are demanded. Chemical treatments that provide passive and inhibitive characteristics aid somewhat in resisting corrosion and are good as bases for subsequent paint coatings.

In equipment in which magnesium is joined to another type of metal, additional precautions must be taken to prevent galvanic corrosion. The speed at which corrosive action between any two metals takes place is dependent upon the relative electrical potential of the two metals in the series. The farther apart they are in the series, the greater will be the corrosive action. It will be noted in Table 8.6 that magnesium and magnesium alloys occupy the top positions among the commercial metals in the series. Magnesium is attacked much faster when joined with brass, bronze, or copper than when joined with steel, although even with the latter the rate of attack is severe enough to cause trouble. The potential between aluminum or zinc and magnesium is small, and practically no difficulties are encountered with these combinations. Aluminum alloy (52-S) rivets are used successfully for joining magnesium sheets.

In controlling galvanic corrosion, it is important to select a combination of metals as close together as possible in the galvanic series and to insulate the dissimilar metals whenever practical. When steel must be joined to magnesium in an assembly, the steel parts should be first cadmium- or zinc-plated and the aluminum should be painted with a zinc chromate primer.

Mechanical Finishes for Magnesium. Unlike aluminum-base materials, magnesium is seldom if ever used in the bare or polished condition. For the most part, magnesium die castings are finished with organic coatings following definitely prescribed systems of chemical treatments and the application of inhibitive primers. Mechanical finishing is necessary, however, to prepare the castings for such treatment.

Surface irregularities are best removed by polishing or grinding on a built-up cloth wheel setup with 100- to 220-grit abrasive. The coarseness of grit will depend upon the extent of the polishing operation. "Dry" polishing or grinding is resorted to only when considerable polishing is required, since the cutting action of a dry wheel is much faster.

To obtain a satisfactory surface on most die castings it is only necessary to use a polishing operation known as *oiling* or *greasing*. The same type of polishing wheels and the same abrasive are used as noted above. The final polish before buffing should be done on a 220-grit wheel, using grease, or on a loose buff, using a greaseless polishing compound such as Lea grade L or C. When these compounds are used, time may be saved in the buffing operation. When greaseless polishing compound is used, 6- to 10-in. sewed or string buffs running at a peripheral speed of 3,600 to 5,000 fpm are recommended. Buffs should not be too closely sewed; ½- to 1-in. circles or loosely sewed pocket-type buffs are most satisfactory.

TABLE 8.6. GALVANIC SERIES FOR METALS AND ALLOYS IN SEA WATER

Anodic (Corroded) End

Electromotive series		Practical series
Metal	Volts	Metal and alloys
Magnesium	−1.55	Magnesium
		Magnesium alloys
		Zinc
		Galvanized steel
Aluminum	−1.33	Aluminum 52S-H
		Aluminum 3
		Aluminum 53S-T
		Alclad
Zinc	−0.76	Cadmium
		Aluminum A17S-T
		Aluminum 24S-T
Chromium	−0.56	Mild steel
		Wrought iron
		Cast iron
Iron	−0.44	Iron-13 chromium
		Nickel-resist
		50-50 tin-lead solder
		18-8 S-type 304 (active)
		10-8 S-molybdenum (active)
Cobalt	−0.29	Lead
		Tin
		Muntz metal
		Manganese bronze
		Naval brass
Nickel	−0.23	Nickel (active)
		Inconel (active)
Tin	−0.14	
Lead	−0.12	Yellow brass
		Admiralty brass
		Red brass
Hydrogen	0.00	Copper
		Silicon bronze
		70-30 copper-nickel
Antimony	0.1	Nickel (passive)
Copper	0.34	Inconel (passive)
		Monel
		18-8 S-type 304 (passive)
		18-8 S-molybdenum (passive)
Silver	0.8	Silver
Gold	1.36	Gold

Cathodic (Protected) End

Die castings requiring a high luster are buffed with a tripoli composition on a loosely sewed buff. Best results are obtained by using a buff having a cloth thread count of approximately 74 to 82 and by operating it at a peripheral speed of 6,000 to 8,000 fpm. Buffs usually are 10 to 14 in. in diameter.

To produce a very high finish on magnesium die castings, a coloring operation is required using canton-flannel buffs. These should be operated at a peripheral speed of 8,000 to 12,000 fpm, and the pressure of the casting should be light. A dry line buffing powder and a 12- to 16-in.-diameter buff are recommended.

Scratch brushing, sand blasting, shot blasting, and similar methods of mechanical finishing are used only to a limited extent on magnesium die castings.

Inflammable dust that may become highly explosive when mixed with the right amounts of air is produced during the grinding and polishing of magnesium. It is therefore important that the dust from these operations be removed as quickly as it is formed. This is accomplished by a specially designed dust-collecting system. In such a system, the dust is conveyed to a settling tank, where it is precipitated into a sludge by a heavy spray of water or light oil. The dust or sludge is not allowed to accumulate in the ducts through which it moves. The sludge tanks or pits are adequately ventilated to prevent the accumulation of the hydrogen gas that is generated by the action of water on the fine magnesium particles. The whole system should be designed to keep dust from getting on workmen's clothes or collecting on the floor or any other exterior part. Dry dust-collecting systems that do not use water or other fluids to precipitate the dust are definitely not recommended for magnesium.

Cleaners for Magnesium. Before a chemical, organic, or electroplated finish is applied to magnesium, all dirt, oil, oxides, and other impurities must be removed from the surface. One of the following cleaning methods usually is employed:

Solvent Cleaning. Vapor degreasing methods are satisfactory when large amounts of oil or grease are to be removed. These methods are not recommended where they are preparatory to some of the chemical treatments described later, unless degreasing is followed by cleaning in a boiling solution of 2 to 5 per cent caustic soda for from 5 to 10 min or by treatment in other strong alkaline cleaners.

Alkaline Cleaning. Cleaners of the strongly alkaline type, such as commonly used on steel, are the most satisfactory. Cleaning may be by boiling or by cathodic electrolytic methods. A satisfactory degreasing solution, which may be used either as a boiling or as an electrolytic cleaner, consists of 4 oz trisodium phosphate, 4 oz sodium carbonate, 0.1

oz soap, and enough water to make 1 gal. The soap may be replaced with a suitable wetting agent to ensure freer rinsing. This cleaning solution is operated at 195 to 212°F. When used as a dip cleaner, the bath should be agitated if it is operated below the boiling point. The time required for cleaning is 5 to 15 min, depending upon the nature and amount of oil or grease on the surface of the casting.

As an electrolytic cleaner, the solution may be operated below the boiling point without the necessity of agitation, since this is afforded by gas evolution on the surface of the work. The magnesium casting is made the cathode in the cleaning solution, and a direct current of 10 to 20 amp/sq ft of surface is applied. The only advantage in electrolytic cleaning is that the desired oil or grease removal is effected in a shorter time, only 1 to 3 min usually being required.

Acid Cleaning. Oxides or dirt remaining on the surface after alkaline cleaning may be removed by a chromic-acid cleaning solution. Chromic acid does not attack the metal, but will dissolve the oxides. The cleaning bath is made up of 1.5 lb chromic acid and enough water to make 1 gal. The castings are immersed for from 1 to 5 min in this bath, which is operated at 195 to 212°F. If chloride ions are present in the water, the bath deposits an insoluble film of oxide on the surface, which is detrimental to subsequent chemical treatment. Water having an appreciable chloride content can be used only if a small amount (usually 0.1 per cent) of silver nitrate is added to precipitate the excess chlorides. The silver nitrate is first dissolved in a small amount of water and then added to the bath.

Electroplating Finishes. Although many attempts have been made in the past to develop a practical method for the electrolytic deposition of metals on magnesium and its alloys, it is only recently that a process which is said to be quite successful has been evolved by the Dow Chemical Company.

In this process, a thin coating of metallic zinc is first deposited on the casting. The zinc bath that is used is quite different from the strongly alkaline sodium-zincate bath used for aluminum; it consists of 12 per cent tetrasodium pyrophosphate, 4.0 per cent zinc sulfate, 1.0 per cent potassium fluoride, and 0.5 per cent potassium carbonate. The pH of the solution is held between 10.2 and 10.4, and the temperature between 170 and 180°F. Time of immersion averages about 5 min.

After the deposition of the zinc film, the plating is done in regular commercial plating solutions as described previously under zinc and aluminum electroplating: a copper strike is applied over the zinc immersion coating, a nickel plate of the proper thickness is deposited over the copper, and the finish coating—chromium, silver, gold, or another metal—

finally is added. With this method, electrodeposits of metals on magnesium are said to possess excellent adhesion resistance to wear and resistance to accelerated-corrosion tests and other tests conducted indoors. No data are available on the ability of such deposits to withstand severe exposure conditions, but tests are in progress.

In the electroplating of magnesium, it is well to bear in mind that complete and continuous coverage of the base metal is absolutely necessary, since if there are any exposed areas, galvanic corrosion is apt to occur.

Chemical Treatments for Magnesium. The chemical treatment used on magnesium die castings listed in Table 8.7 are used (1) for primarily inhibiting corrosion; (2) as a base for organic coatings; and (3) to a limited extent, for decoration.

A chrome-pickle treatment is normally given all magnesium die castings to protect the metal during shipment, storage, and machining. The coating produces a passive surface and etches the metal so that good paint adhesion is assured. Under normal service conditions, the coating is a satisfactory paint base. The treatment will remove from 0.0006 to 0.002 in. of metal from the surface and is therefore not recommended for machined surfaces on which close dimensional tolerances must be held.

Either of the solutions shown in the table may be used for this treatment. The temperature of the solution is maintained at 125 to 135°F. The time of treatment is 10 sec. After removal from the solution, the die castings should be exposed to the air for about 5 sec before being rinsed thoroughly in cold and hot water to facilitate drying.

An additional treatment, which increases corrosion resistance, consists of boiling the casting in a dichromate solution after the conventional chrome-pickling operation; this treatment is known as the "sealed chrome pickle." The die casting is immersed in a bath containing 1 to 2 lb dichromate (sodium, potassium, or ammonium) per gal of water. The bath is maintained at boiling temperature, and time of treatment is 30 min. The dichromate solution is controlled by additions of chromic acid to maintain the pH between 4.0 and 4.4.

Hydrofluoric-dichromate Treatment. When the maximum in protection against corrosion and the ultimate in paint adhesion are required, either a hydrofluoric-dichromate or a hydrofluoric-alkaline-dichromate treatment is specified. The color of the coating produced by these treatments is brown or black; practically no change in dimensions results from this method of finishing. In the hydrofluoric-dichromate treatment, the parts are first cleaned and then immersed for 5 min in a solution containing 15 to 20 per cent by weight of hydrofluoric acid. A satisfac-

TABLE 8.7. CHEMICAL TREATMENTS FOR MAGNESIUM DIE CASTINGS

Dow No.	Treatment	Composition of solution: Material	Composition of solution: Amount	Time of immersion	Applications
1	Chrome pickle	Sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$) Concentrated nitric acid (1.42 sp gr) Water	1.5 lb 1.5 pints To make 1.0 gal	10 sec	For protection during storage and shipment. Satisfactory as a base for organic finishes.
	Chrome pickle	Chromium trioxide (CrO_3) Concentrated nitric acid Water	1.0 lb 0.9 pints To make 1.0 gal	10 sec	
	Sealed chrome pickle	Sodium, potassium, or ammonia dichromate Water	1.0 to 2.0 lb To make 1.0 gal	30 min	Supplemental treatment after chrome pickle to increase corrosion resistance.
4	Chrome alum	Potassium chrome alum Sodium dichromate Water	4.0 oz 13.3 oz To make 1.0 gal	......	Used only as a black decorative finish. Satisfactory as a base for organic finishes.
6	Caustic pressure	....	....	......	Protective and decorative hard finish. Available in a variety of colors. Not a good paint base.
7	Hydrofluoric dichromate	Hydrofluoric acid (48 to 52 per cent conc) Water	1 part 2 parts	......	Provides maximum protection and paint adhesion for all types of exposure.
9	Hydrofluoric alkaline dichromate	Ammonium sulfate Sodium dichromate Ammonia (0.88 sp gr) Water	4 oz 4 oz ⅛ fluid oz To make 1.0 gal	......	Galvanic amodized. Satisfactory paint base for all exposures.
12	Caustic anodize	....	....	......	Protective and decorative finish. Available in a variety of colors. Not a good paint base.

tory bath may be prepared by diluting one part by volume of technical-grade hydrofluoric acid having a concentration of 48 to 52 per cent with two parts by volume of water. Next, the castings are rinsed thoroughly in cold running water and then boiled for at least 45 min in a solution containing from 1 to 1½ lb sodium dichromate per gallon. The last step is a rinse in hot and cold running water to facilitate drying.

The hydrofluoric acid bath is very slowly depleted in use. The concentration should be maintained at between 10 and 20 per cent. It can be checked by titration with sodium hydroxide by the use of phenolphthalein indicator. This is done by diluting a 2-ml sample of the hydrofluoric acid solution with at least 100 ml of distilled water. A drop

or two of phenolphthalein indicator is added, and the diluted solution then is titrated with $1N$ NaOH solution until a permanent pink color is produced. The number of milliliters of $1N$ NaOH required for the titration is approximately equivalent to the percentage of hydrofluoric acid in the bath. A pipette for obtaining the bath sample may be made by lining a 3- or 4-ml glass pipette with paraffin wax and calibrating it to indicate a 2-ml volume; a rubber bulb should be used for drawing the sample into the pipette.

Depletion of the dichromate bath will also be slow and will be indicated by a nonuniformity of coating or by an increase in the time necessary to produce a coating. Good control can be obtained by maintaining the pH of the solution between 4.5 and 5.5 by additions of chromic acid.

Containers for the hydrofluoric-acid solutions should be lead-lined, although some types of rubber lining, such as Koroseal linings, have been used successfully. Steel, aluminum, or almost any of the commonly used tank materials are satisfactory for the dichromate solution; this tank should be fitted with a loose cover to minimize evaporation.

Hydrofluoric-alkaline-dichromate Treatment. This treatment is similar to the hydrofluoric-dichromate process except that an alkaline-dichromate bath is used. After adequate cleaning, the parts are immersed for 5 min in a 10 to 20 per cent by weight solution of hydrofluoric acid. This solution is identical with the solution in the preceding treatment. The parts are washed thoroughly in cold running water and then boiled for 45 min in a bath consisting of 4 oz ammonium sulfate, $(NH_4)_2SO_4$, 4 oz sodium dichromate, $Na_2Cr_2O_7 \cdot 2H_2O$, $\frac{1}{3}$ fl oz ammonia having a specific gravity of 0.880, and water to make 1 gal. The parts are again washed in cold running water and then boiled for at least 5 min in a solution containing 1 oz arsenous acid (As_2O_3) per gallon.

The control of the hydrofluoric solution is the same as previously outlined under the hydrofluoric-dichromate treatment. The alkaline-dichromate bath is controlled by the color of the coatings and the pH of the solution. Depletion of the bath is indicated by nonuniform or pale coatings, by slowness of coating formation, and by an increase in the pH of the bath to about 6.2. To revivify the bath, a solution containing equal parts by weight of chromic acid (CrO_3) and concentrated sulfuric acid (sp gr 1.84) is added until the pH of the bath is decreased to 5.6; a pH of 5.6 to 6.0 represents the best operating range.

The arsenous acid bath depletes very slowly. Because of the low cost of this bath, no control is advocated. Instead, the bath is discarded periodically, the frequency depending upon the amount of use.

Chrome-alum Treatment. The chrome-alum treatment produces a decorative black finish with very little change in dimensions. The coat-

ing is a good paint base but is not so protective as the treatments described previously. It is not recommended for prolonged outdoor exposure or severe service.

After adequate cleaning, the parts are immersed in a glass-lined or pure aluminum tank containing a boiling solution of the following compositions: 4 oz potassium chrome alum, $K_2Cr_2(SO_4)_4 \cdot 24H_2O$; 13.3 oz sodium dichromate, $No_2Cr_2O_7 \cdot 2H_2O$; and water to make 1 gal. The time of treatment to secure a black color may range from 2 to 15 min, depending upon the freshness of the solution. Upon removal from the bath, the parts are rinsed thoroughly in both cold and hot water.

Treatment in a depleted chrome-alum solution results in the formation of a superficial layer of brown powder which may be removed by wiping or tumbling the castings in sawdust or other suitable material. The solution may be revivified by additions of sulfuric acid, not exceeding $\frac{1}{3}$ fl oz/gal, or sufficient to just redissolve the brown precipitate that settles out during treatment. The solution should be boiled to dissolve the precipitate. The solution may be revived in this manner about five times, after which it should be discarded. Control is best effected by additions of sulfuric acid to maintain the pH between 2.5 and 3.5; the pH of a depleted solution is 5.5.

Selection of Chemical Treatment. Selection of the proper chemical treatment will depend largely upon service conditions. For interior use, the chrome-pickle coating is a satisfactory paint base. In many cases, no chemical treatment may be needed if the subsequent organic finish is compatible with the metal surface. For ordinary exterior service, the chrome-pickle treatment also is adequate if corrosive conditions are not severe. Here again, it is possible to eliminate chemical treatment provided that a proper choice of primer is used. For severe exterior service, maximum protection and paint adhesion are assured by the use of hydrofluoric-dichromate, the hydrofluoric-alkaline-dichromate, or the sealed-chrome-pickle treatments.

Organic Finishes for Magnesium. Magnesium die castings should be finished with an organic paint immediately after chemical treatment if such is the prescribed finish. If this cannot be done, the surface usually becomes contaminated, and a final cleanup is necessary before painting. Vapor degreasing has proved satisfactory in commercial practice. An alternate method utilizes a solvent wipe or wash; the solvent should be similar to that used as a diluent for the finishing coat. The use of hot alkaline cleaners is not recommended, since they may impair the chemical coating.

In general, magnesium is painted with the same procedures as other metals. Air-dried primers are usually applied over the chemically treated

surface. Finish coats must be compatible with this primer to ensure satisfactory adhesion.

The choice of the finishing coatings is governed by the conditions to be encountered in service. For interior use, organic finishes normally are chosen for their decorative value. These may be high-gloss japan or enamel finishes or possibly crystal. Both air-dried and baked finishes can be used. One and two coats can be employed, depending upon such variables as surface treatment of die castings, choice of finishing materials, and conditions of service.

TABLE 8.8. ORGANIC FINISHES FOR MAGNESIUM-BASE DIE CASTINGS *

Service conditions	Chemical treatment	Organic coating			
		Primer		Finish	
		No. of coats	Type	No. of coats	Type
Interior	None †	None	....	1 to 3	Clear lacquer
	Chrome pickle	1	Baked	1 or more	Air drying, baked, or novelty
	Chrome pickle	1	Air drying	1 or more	Air drying, enamel, or novelty
	Chrome pickle	None	....	1 or more	Baked japan or novelty
	None	1	Baked	1 or more	Baked japan or novelty
	None	1	Special air drying	1 or more	Compatible enamel or novelty
Ordinary exterior	Chrome pickle	1	Baked	2 or more	Air-drying or baked enamel
	Chrome pickle	1	Air drying	2 or more	Air-drying enamel
	None	1	Baked	2 or more	Baked enamel
	None	1	Special air drying	2 or more	Air-drying enamel
Industrial atmosphere	Hydrofluoric-dichromate	2	Baked inhibitive	2 or more	Baked enamel
	Hydrofluoric-dichromate	2	Air-drying inhibitive	2	Air-drying enamel
	Hydrofluoric-alkaline dichromate	2	Air-drying inhibitive	2	Air-drying enamel
	Sealed chrome pickle	2	Air-drying inhibitive	2	Air-drying enamel

* All castings finished without prior buffing or polishing, except where noted.
† Buffed prior to finishing.

Exterior exposure such as is encountered in aircraft, marine, and similar applications normally necessitates a four-coat finish. For this type of service, two coats of inhibitive primers, such as Navy F-27 or Army 14-080, are recommended, followed by two finishing coats. The finishing coats for this service should possess maximum impermeability.

Baked finishes have several advantages over air-dried finishes, namely, decreased drying time, better adhesion, and increased resistance to abrasion. In addition, intricate castings may contain porous areas in which moisture or air is entrapped, and a baking schedule will force out any

water or gases from these porous areas without harming the primer. If the first coat contains "craters" or "pimples" which are indicative of minute gas pockets underneath, the castings should be preheated long enough at the regular baking temperature to drive off any interfering gases. It is good practice then to apply the finishing coat while the castings are still warm.

The recent development of infrared baking has been of considerable importance in speeding up the drying time in commercial finishing. Although baking finishes are usually adaptable to infrared radiant drying, paint manufacturers have cooperated by modifying their formulations to conform more suitably to the best practices of this newest method of baking.

A summation of these data on organic finishes, including the recommended chemical treatments for different exposures, is given in Table 8.8.

FINISHES FOR COPPER-BASE ALLOYS

Brass, because of its high corrosion resistance and attractive appearance, seldom is finished by other than mechanical means; the same general procedures described for mechanically finishing zinc, aluminum, and magnesium can be applied. Polishing, buffing, brushing, burnishing, and similar techniques are employed.

Electroplated, chemical, painted, or sprayed metal finishes are used much less frequently. As a matter of fact, it is only for special applications that these finishes are used at all, because another more adaptable alloy for die casting, such as zinc or aluminum, is usually specified if plated or organic finishes are required. However, if a copper-base alloy is essential and finishing is required, the techniques recommended for machined and fabricated parts can be used for brass die castings.

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CHAPTER 9

MACHINING OF DIE CASTINGS

Die-casting alloys are comparatively soft and free-cutting. Magnesium has perhaps the best machining qualities of any of the metals, and the low power required for machining it permits heavier cuts (at moderately high speeds) than are possible with zinc, aluminum, and brass. However, these alloys are also quite free-machining, zinc having the best machining qualities in this group, and brass the poorest.

Ordinarily, hardened high-carbon steel or high-speed steel is used for all machining operations except tapping and certain types of threading. Carbide tools also are quite common, since fewer tools are required, tool life is better, and a higher degree of finish and accuracy can be maintained.

The major difficulty that may be encountered in machining die castings is the soldering of the metal to the cutting edge of the tools. This condition can be minimized by setting the tools correctly, providing proper rake and clearance angles, polishing the tool surfaces or clearance spaces, avoiding drag by reducing the surface of the tool in contact with the work, using the proper lubricant, and choosing the correct machining speed in relation to feed.

Plenty of chip room is required on all tools to provide a free cutting action and to prevent excessive loading or packing of chips. Light cuts should be avoided as much as possible. The cut should be deep enough to penetrate the outer surface of the cast metal; this outer surface tends to be harder than the base metal because of its abrasive content and therefore it is advisable to remove at least 0.005 to 0.010 in. of stock whenever possible.

Lubricants and/or coolants generally are required when close tolerances, improved speed of production, and fine finishes are necessary. This is true when machining brass and, to a certain extent, when machining zinc, although the latter metal is often machined dry. A lubricant is necessary for all operations except turning when machining aluminum. With magnesium, a coolant is required to dissipate the heat and reduce the fire hazard.

Best results on die castings usually are obtained with a light, neutral oil. On magnesium, a light mineral oil may prove better. Tallow may

be used to make chips adhere to the tool when working with any of the alloys, but it is not satisfactory as a lubricant.

DRILLING

Carbon-steel or high-speed-steel drills are used in drilling die castings. For light drilling operations, such as when drilling shallow holes or removing flash from holes, a carbon-steel drill is more economical. For more severe drilling operations, such as on extra-deep holes, high-speed-steel drills of the high-spiral type are recommended. Where production requirements and other considerations warrant the additional expense, carbide-tipped drills can be used to advantage since they increase the number of pieces that can be drilled before resharpening becomes necessary.

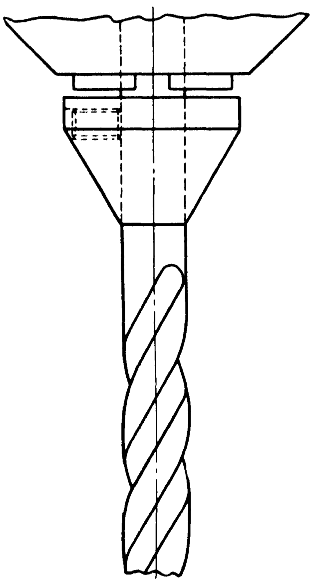


FIG. 9.1. Chip deflector on drills prevents chips from wedging into the jaws of the chuck.

The drill must be ground so that the chips are cleared from the tool and fed away from the cutting edge. If standard drills are used, there may be a tendency for the cutting edge to load; polishing of the flute adjacent to the cutting edge helps to relieve this condition.

Sometimes a long chip follows along the drill and becomes wedged into the openings between the jaws of the drill chuck, thus stopping the chip movement and loading the drills to the extent that cutting ceases. This condition can be avoided by making a chip deflector such as is shown in Fig. 9.1. It is a tapered collar that is located adjacent to the chuck, through which the drill is placed. For best results, the chip deflector taper should be located in relation to the runout of chip clearance of the drill to remove all obstructions for the flow of chips.

Conventional methods of drill grinding and drilling procedures are followed, as shown in Table 9.1 and Fig. 9.2. For zinc, aluminum, and copper, the included angle of the point between the cutting edges is generally 118 deg. For special work, this angle may be varied from 90 to 136 deg. Flatter points prevent the drill from running out when deep sections in which porosity may be encountered are being drilled; sharper points are used to minimize burr in breaking through at the end of the

hole. With sharp points, a vertical flat is ground along the lip to provide a zero or slightly negative rake along the cutting edge and thus counteract any "corkscrew" or grabbing tendency. A lip-clearance angle of 12 deg works satisfactorily in most drilling, but is often increased to 15 deg. The angle between the cutting edge and a line across the dead center of the drill should be between 120 and 135 deg.

TABLE 9.1. DRILLING OF DIE CASTINGS

Drill	Die-casting alloy: Zinc, aluminum, magnesium, and brass
Type	High-speed steel for deep holes; carbon steel satisfactory for shallow holes; high-spiral angles for more severe operations.
Grind	From 90 to 136 deg included angle, with 118 deg used in most cases; from 12 to 15-deg lip-clearance angle with small flat. On sharp-pointed drills, a small vertical flat is ground across the lip to prevent "corkscrew" or grabbing tendency. From 120 to 135 deg angle between the cutting edge and a line across the dead center of the drill.
Flutes	Large, deep, and highly polished.
Speed	Determined by trial: from 300 to 700 fpm for brass, maximum speed of machine for magnesium. Feeds usually from 0.002 to 0.010 in./rev.
Lubricant	Usually necessary for brass, magnesium, and aluminum; not always necessary for zinc. In the case of magnesium the use of lubricants is primarily for cooling the work, the improvement of surface finish being of minor importance. The choice of lubricants or coolants for magnesium must be limited to oil-base materials. Water solutions of any kind including water-soluble oils are definitely not recommended because magnesium chips wetted with water will ignite readily, while chips thoroughly soaked in oil cannot be easily ignited.

Flutes that are larger than normal are an advantage. Thick-webbed drills are stronger than thin-webbed types; but when they are used, it is desirable, if not essential, to thin the web near the point. Straight fluted drills also give satisfactory service under certain conditions when chip removal is very slight, such as is encountered in shallow holes or when removing a small amount of stock from a cored hole. These are usually stepped or formed drills.

The proper relationship between the speed and the feed of the drill is necessary to prevent soldering of the metal on the cutting edge. High speeds are recommended for drilling brass; best results are obtained by using as fast a speed and as high a feed as are practicable without causing excessive tool breakage.

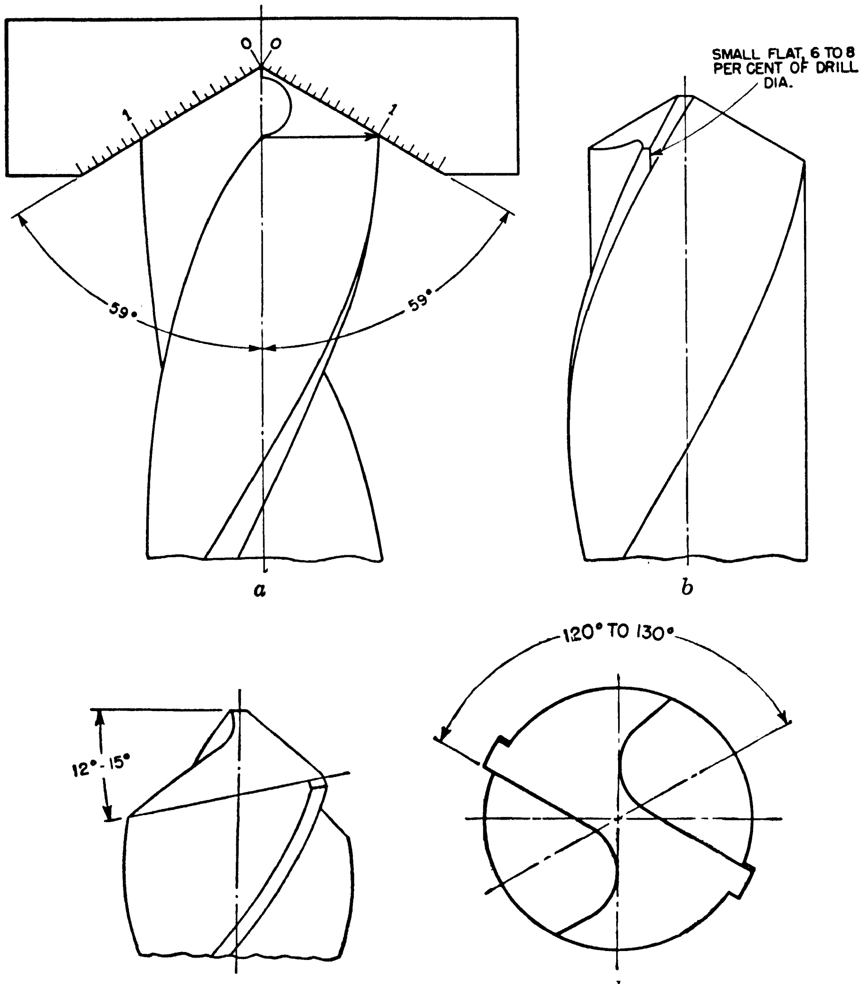


FIG. 9.2. Tool design for drilling die castings: *a*, standard 118-deg angle between the cutting edges for most operations; *b*, a small flat with 0-deg rake counteracts "cork-screw" or grabbing tendency if sharp points are necessary; *c*, lip clearance of 12 to 15 deg; *d*, from 120 to 130 deg included angle between the cutting edge and a line across the dead center of the drill.

Most drilling of zinc castings is done dry, but for some high-speed production drilling it is sometimes necessary to use a lubricant. A lubricant should always be used when drilling aluminum- and magnesium-alloy castings.

Lubricants or coolants also are necessary for drilling brass. Coolants keep the temperature of both the tool and the work uniform, thus ensuring greater accuracy of the finished product. Another and very important consideration is the removal of chips by the washing action of the coolant.

TAPPING

To cast threads in die-cast parts is not always convenient or practical, especially when the pitch diameter is small or when close tolerances must be maintained. In such cases, the holes are tapped with standard taps and equipment.

TABLE 9.2. TAPPING OF DIE CASTINGS

Tap	Die-casting alloy	
	Zinc, aluminum, and brass	Magnesium
Type	Standard taps suitable. Spiral-point taps for deep through holes; straight-fluted taps for blind holes.	Standard taps for class No. 1 and No. 2 threads; special taps for class No. 3 and No. 4 threads.
Grind	Rake angle of 12 to 15 deg. From 1½ to 2½ thread chamfer for regular square-end taps. Eccentric relief desirable. From 5 to 6 thread chamfer for spiral-point taps. Small lands, from 1½ to 3 times pitch of thread.	Rake angle of 10 to 25 deg; heel-rake angle of from 3 to 5 deg. From 2 to 3 thread chamfer. Cylindrical narrow land.
Flutes	Large to provide chip clearance on all but spiral-point taps. Generally 2 flutes for holes up to ⅜ in., and 1 less than normal for large holes.	2 flutes for holes up to ¼ in., 3 flutes for holes up to ¾ in., and 4 flutes for larger holes.
Speed	By trial. Half of the drilling speed is a good starting point.	By trial. Usually from 75 to 400 fpm.
Lubricant	Not necessary but often desirable for zinc; usually necessary for aluminum and brass.	Use of a light mineral oil or a light neutral oil recommended.

Holes to be tapped are nearly always cored to eliminate a drilling operation prior to tapping. These holes must be tapered. The large

and small diameter of cored holes should be cast to give from a 60 per cent full thread at the large end to a 75 per cent full thread maximum at the small end; at no time should the percentage of threads exceed 75 per cent. As an example, the cored hole for a 10-32 tap should be 0.159/0.166 in., including tolerance and taper. Unless allowance is provided for this condition, or the hole is either drilled or reamed prior to tapping, the results will be excessive tap breakage or poor threads. When drilling holes to be tapped, the accepted standard of approximately 65 per cent full thread should be followed.

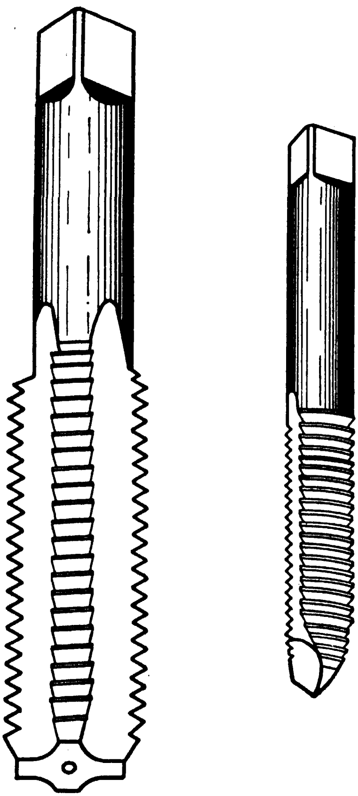


Fig. 9.3. Standard tap (left) and spiral-pointed or gun tap (right). Gun taps are used for tapping deep through holes.

Taps are nearly always of standard types, as indicated in Table 9.2; even the grinding need not be special in many cases. Plenty of chip clearance is desirable. Two-fluted taps for holes up to about $^3/_8$ in. diameter, and taps having one less flute than is standard for other sizes, are preferred. Ground-thread taps, although not essential, are usually employed (especially in sizes above $^1/_4$ in.) since they produce a smoother and more accurate thread.

Taps with special finishes that reduce wear and are highly resistant to abrasive action perform satisfactorily on all die castings, especially those made of brass.

In selecting the type of tap, the nature of the hole is an important consideration. For through holes more than two diameters deep, a *gun tap* (Fig. 9.3), which is also known as a *chip driver* or *spiral-point tap,* should be used. It has a pointed end or *shear;* and the flutes at the end, instead of being straight, are ground off at an angle. This results in shearing the metal and curling the chips, which are forced ahead of the tap. Since the chips are kept out of the flutes, flutes can be shallower than otherwise, and the tap is stronger.

Since lands are wide in taps of this type, there may be considerable friction. Therefore, taps of this type should be used only for short

holes. Although they may be used for blind holes when the cored or drilled holes have plenty of space at the bottom of the hole for chips, the chips are sometimes difficult to remove. Spiral-point taps cut rapidly, but are more difficult to sharpen than a tap in which the flutes are straight throughout its entire length. Chip-driver taps should be reground after each 2,000 holes tapped. Such taps generally have five to six threads of lead. The spiral point always extends beyond the first full thread.

For tapping blind holes, especially those in which the thread must come close to the bottom, a straight-flute tap, square at the end and with

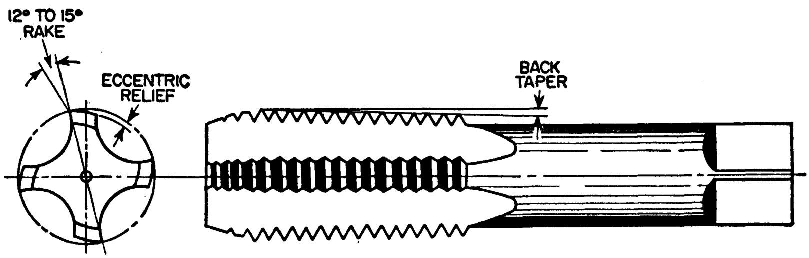


FIG. 9.4. Eccentric relief should be provided on large taps. A rake angle of from 12 to 15 deg is generally satisfactory for all alloys.

a lead of $1\frac{1}{2}$ to $2\frac{1}{2}$ threads, is recommended (Fig. 9.3). Flutes should be large enough to give good chip clearance, and the lands should be narrow to minimize friction. Such taps tend to break up chips. They should have two flutes for holes under $\frac{3}{8}$ in. and three flutes for larger holes. The same tap with more of a point (relieved for five or six threads) can be used for blind holes in which the thread does not come too close to the bottom and for long through holes.

It is good practice to provide a rake of from 12 to 15 deg. On large taps, eccentric relief is sometimes provided, as indicated in Fig. 9.4. This narrows the land to a mere line and reduces friction and chances of galling. Eccentric clearance also facilitates removal of the tap from the hole and prevents it from sticking. With small, conventionally ground taps, sticking can be reduced by grinding off or "breaking" the back corner of the lands.

Any tendency of a tap to pick up metal on the cutting edge can be avoided by keeping the tap sharp and by using a good lubricant. A lubricant also reduces friction and tap breakage and eliminates any tendency for the die-cast alloy to "plate" onto the tap. Higher speeds may also be used, thus increasing production, and much better surface

finishes are obtained than is possible when tapping is done in the dry state.

For holes 1.0 in. in diameter and larger, adjustable or collapsible taps are often used to advantage. They make it easy to vary size and fit of threads and eliminate the need for reversing the tap. Tungsten-carbide taps are also efficient in the larger sizes, greatly reducing wear and the necessity for frequent grinding. They are especially effective on high-production jobs.

In selecting taps for tapered pipe threads, the recommendations for bottoming taps should, in general, be followed. Some rake and some relief are desirable. The interrupted-thread type of tap should be used.

In tapping, as in drilling, there is no definite rule as to the best cutting speed beyond the obvious one of using the highest speed that will give satisfactory results. Some experimenting with speeds may be required. One-half the drilling speed is an approximate starting speed for average jobs. High-speed tappers are extensively used, and in some cases from 1,000 to 4,500 small holes per hour can be tapped, depending upon the number of holes per piece and the time required to bring the work into position.

THREADING

In many cases, external threads are required on die castings. Sometimes these threads are cast, but cast threads usually are not accurate and have a parting-line flash across the threads. To obtain accuracy it is necessary to chase the thread after it is cast. Under such circumstances it is more economical to cast a male blank to the correct size and cut the full thread after casting.

Threading can be done successfully with button or acorn dies in small sizes, but on large sizes the chaser-type die should be employed (Fig. 9.5). Straight-milled chasers are found to be most practical; these may be of either the radial or the tangent type. In the case of the radial form, a 10-deg hook is used for straight threads and a 7-deg hook for tapered threads. The best surface speeds are from 50 fpm for from 3½ to 7½ threads per inch; 100 fpm for from 8 to 11 threads per inch; and 200 fpm for from 12 to 32 threads per inch. An average speed is 10 to 15 per cent slower than tapping, as indicated in Table 9.3. The cutting edge of the chaser should be on center to eliminate wearing of the chasers just behind the cutting edge. Figure 9.5 shows the grind for this type of cutter when used for aluminum or zinc. It involves a 5-deg rake. With this type of grinding, approximately thirty thousand ¾-24 threading operations can be performed between cutter grinds. In the case of

round dies for aluminum and zinc, a rake of from 15 to 20 deg is specified, with narrow cutting sections and eccentric relief on sizes of $\frac{7}{16}$ in. in diameter and larger.

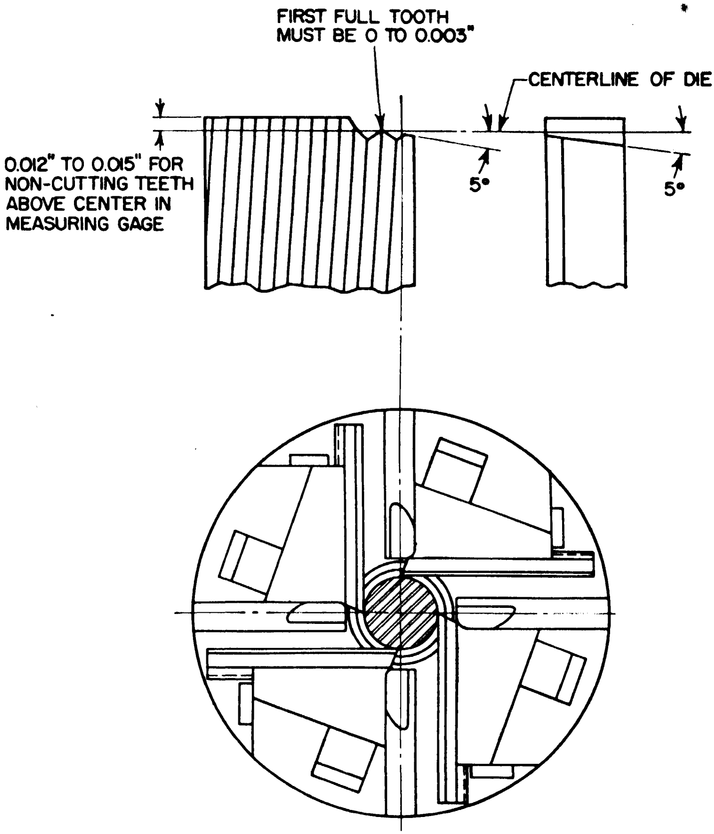


Fig. 9.5. Chaser-type die for threading die castings. With a die of this type, approximately thirty thousand ¾-24 threading operations can be performed between grinds when working with zinc or aluminum parts.

For cutting brass, the front face of each die chaser should lie in a plane intersecting the axis of the die (zero rake). The throat or chamfered edge of each chaser should have clearance in back of the cutting edge or in a circumferential direction. This clearance should be just enough to ensure a free cutting action. If there is not enough clearance or relief, the cutting action will be retarded. It is of special importance that die chasers for brass have as little clearance as possible, because the throats of the chasers steady the die when starting a thread. The sides

of the chaser teeth, instead of the leading edges or corners, are sometimes relieved when cutting a thread close to a shoulder.

TABLE 9.3. THREADING OF DIE CASTINGS

Tool	Die-casting alloy	
	Zinc, aluminum, and brass	Magnesium
Type of die	Button and acorn dies for small work; chaser dies with straight-milled chasers, either radial or tangential, for larger sizes.	Thread chasers and threading dies. Self-opening dies for threads of maximum smoothness.
Grind of die	At least 7-deg rake for milled- or hobbed-type chasers for aluminum and brass; 0 rake but 7-deg snub for brass.	About same cutting angle as taps, with lands as narrow as possible to provide chip clearance.
Threading speeds	From 10 to 15 per cent slower than for tapping. For brass, from 50 to 150 fpm will handle most jobs; for aluminum, speeds about equal to those for magnesium are used.	Up to 1,000 fpm; generally about 475 fpm for 18 threads/in., 325 fpm for 14 to 18 threads/in., 250 rpm for 9 to 14 threads/in.
Lubricant	Usually required on aluminum. Not always necessary for zinc or brass.	Recommended for best results.

Dies that open automatically to permit removal of the threads when they are finished not only save time, but may prevent the injury to the thread that occurs when the chips wedge between the teeth of a non-opening die and the workpiece when the die is reversed. Lead screws, which help when feeding the dies onto the work, are sometimes necessary when threads must be cut to close tolerances.

REAMING

Reaming of holes in die-cast parts is frequently necessary when close tolerances must be maintained. High-speed-steel reamers are usually satisfactory, although tungsten-carbide tools may be warranted for high-production parts or when extremely close tolerances must be held. Often a reaming operation is done with a combination tool that reams, counterbores, and chamfers; or that reams, chamfers, and spot-faces. Two such tools are shown in Fig. 9.6. By combination operations, setup time is reduced to a minimum and production is increased to an extent that more than offsets the higher cost of such special tools.

Most of the cutting with a reamer is done by the nose end, which is beveled to 45 deg to provide a lead. If the initial grinding of the flute and land is correct, little other grinding is required, except at the lead end where a light cut may be taken off the radial face of the flutes. In grinding the lead bevel, a clearance angle of 10 deg is advocated. An important consideration is to have the cutting edge keen. The faces of flutes are made radial (zero rake), and the clearance angle behind the land generally approximates 10 deg. A back taper from nose to shank of about 0.001 in. is used.

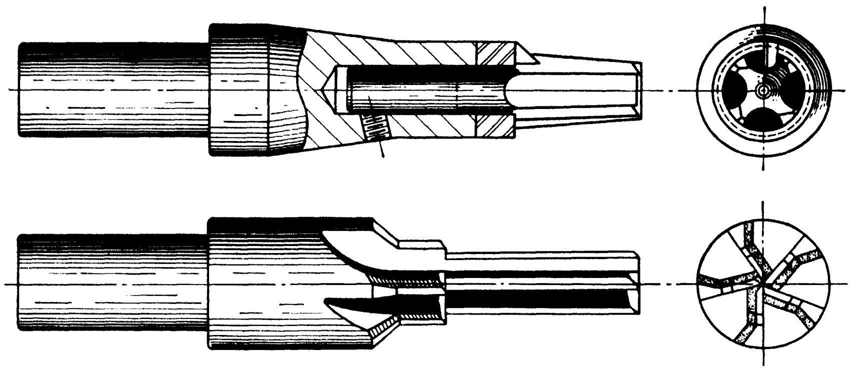


FIG. 9.6. Combination reamers. The tool shown above is used to ream, counterbore, and chamfer; while that below to taper, ream, and chamfer.

Machine reamers commonly used for zinc and aluminum have six or eight flutes. Spiral flutes with a very marked spiral are necessary for reaming holes having a keyway. In the case of deep-hole reaming, better results are obtained by using reamers with left-hand flutes and right-hand cutting edges. Rose reamers are not recommended. Deep flutes are advised, and polished flutes have been found to avoid loading.

For reaming brass die castings, fewer flutes than normal give the most satisfactory results because more chip room can be obtained between teeth and a free cutting action results. Little or no rake prevents "hogging in" of the tools (Table 9.4). Most reamers are of the rose-reamer type in that they cut on the chamfer portion of the tool; this refers to straight-hole reaming only. At times it is necessary to grind teeth on the front end of the reamer (Fig. 9.7). It then acts as a boring tool and, when properly guided, will not follow the rough hole.

The land width of reamers should not exceed 0.015 in., but this is often ground down to around 0.005 in. to obtain freer cutting, less loading tendency, and reduced heating. Wide lands tend to generate heat, some-

TABLE 9.4. REAMING OF DIE CASTINGS

Reamer	Die-casting alloy		
	Zinc and aluminum	Brass	Magnesium
Type....	Standard, with deep flutes and narrow lands. Inserted-blade reamers satisfactory if rigid.	High-speed, fluted chucking reamers with special clearance. Tungsten-carbide reamers on high-production jobs. Expanding chucking reamers for close tolerances.	Standard, with deep flutes. Usually high-speed steel. Carbon steel and carbide reamers also satisfactory.
Grind....	0.015-in. max land, 10 deg-0-rake clearance on lands and lead bevel.	0.010- to 0.015-in. land. 0-deg rake. No radial clearance on rose chucking reamers.	0.010- to 0.025-in. land. 15- to 20-deg clearance angle; 5- to 8-deg rake angle; 15 to 20-deg end clearance; 0- or 10-deg helix angle.
Flutes....	Polished. Large.	Less than required for steel or cast iron. Can be straight or spiral.	Fewer than required for other materials. About 4 flutes with reamer under 1.0 in. diameter, about 6 flutes for large diameter.
Speed....	By trial.	From 100 to 400 fpm, determined by trial.	From 100 to 400 fpm. High cutting speeds and medium feeds for best finish.
Lubricant.	Not always necessary for zinc. Required for aluminum.	Required in nearly all cases.	Usually required to reduce fire hazard and obtain fine finish.

times causing the hole to expand and resulting in an undersized hole after the reamer is removed and the die casting is cooled. It is good practice to let the work float, or to use a floating reamer, rather than to fasten the work solidly while reaming.

When $\frac{1}{32}$ in. or more metal is to be removed by reaming, it may be done in either of two ways. All the stock can be removed in one cut with a single land reamer, or the stock can be removed in two steps with a reamer that is ground with a stepped portion at the end, the end being about 0.005 in. smaller than the main body. Step cutting away of most

of the metal leaves the body portion to size the hole with a light cut. Stepped reamers are also used for simultaneously reaming coaxially stepped holes. When the hole to be reamed is of a sufficient size to permit the use of inserted-blade reamers, this type is sometimes preferred.

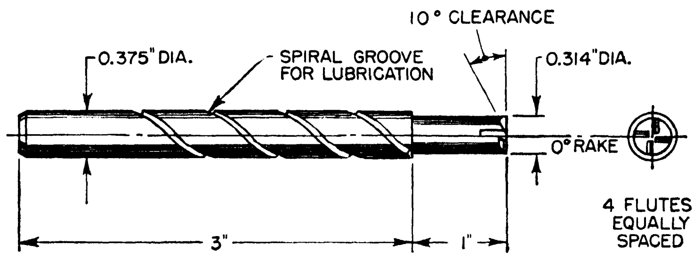


FIG. 9.7. Teeth sometimes are ground on the front of a reamer so that it acts as a boring tool and does not follow the rough hole.

Lubrication is essential in obtaining a fine finish, which is usually required of reamed holes. Coolants may be necessary to hold very close tolerances.

FACING

Facing is performed on die castings to remove flash or ejector-pin marks from a base or other flat surface or to finish the surface to close tolerances. It is often done in a lathe with ordinary lathe tools or, when accuracy is not important, on a belt sander or against flat plates that are

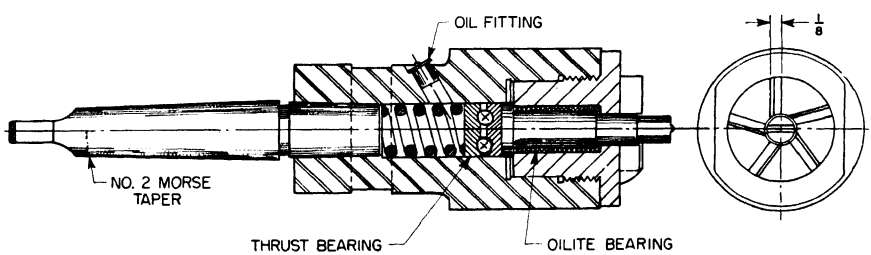


FIG. 9.8. Special tool with center holddown for spot-facing die castings.

covered with sand or emery paper. Spot facing (Fig. 9.8) is more common and often is done in combination with other machining operations such as hollow milling, reaming, or chamfering, as indicated in Fig. 9.9.

The facing tool should have an odd number of teeth—not more than seven—with plenty of chip clearance between them. The faces of the teeth are in radial planes through the axis of the cutter, without rake, as stated in Table 9.5. The clearance angle should be about 12 deg

behind the cutting edge for zinc and aluminum, and from 5 to 10 deg for brass.

In removing heavy flash by facing, the cutting face of the cutter should be turned through an angle of 15 to 20 deg, as shown in Fig. 9.10. This reduces the size of burr. If the fin is on the outer edge of the casting, the chips should be turned toward the center of the part being faced, the metal being sheared toward the solid portion of the casting; if the fin is on the inner edge, the metal should be sheared outward. This practice is advantageous only where the fin is perpendicular to the surface and covers but a portion of the width of the surface being faced.

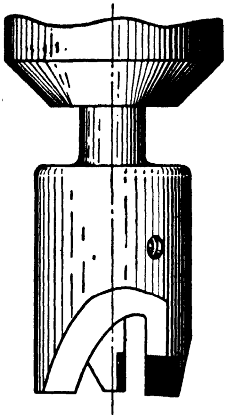


Fig. 9.9. Hollow mill for turning a cylindrical surface and performing a facing operation at the same time.

TURNING

Turning of die-cast parts can be done with carbon-steel tools, but the practice of using tungsten-carbide tools, even on extremely short runs, is more common. Their application on small-quantity jobs is possible since turning lends itself to the use of tools having general-purpose designs adaptable to a number of different jobs. In such cases, the higher initial-investment cost of the carbide tool can be absorbed over a number of applications.

Table 9.5. Spot Facing of Die Castings

Cutter	Die-casting alloy	
	Zinc, aluminum, and magnesium	Brass
Type....	One with odd number of large teeth. Plenty of chip clearance.	Usually custom built with large teeth and plenty of chip clearance.
Grind....	No rake; 12-deg clearance.	0-deg rake; 5- to 10-deg clearance.
Speed....	By trial.	By trial; from 200 to 400 fpm.

For turning cylindrical surfaces of aluminum or zinc with carbon steel, a top rake of from 0 to 20 deg and an end clearance of from 8 to 20 deg (about 15 deg is a good average) are recommended. It is important that

the latter angle be large enough to prevent any drag on the heel of the tool. Where side cutting is involved, a side clearance of about 4 deg is sufficient (Fig. 9.11).

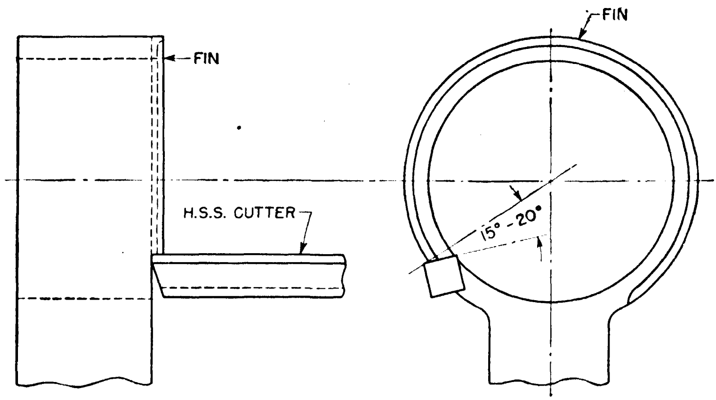


FIG. 9.10. For removing heavy flash by facing, the cutting face of the cutter should be turned through an angle of 15 to 20 deg.

When carbide turning tools are used for zinc or aluminum, the end clearance should not exceed 6 to 8 deg and the top rake should be within 5 to 10 deg. The side-cutting angle may be from 10 to 20 deg, but this

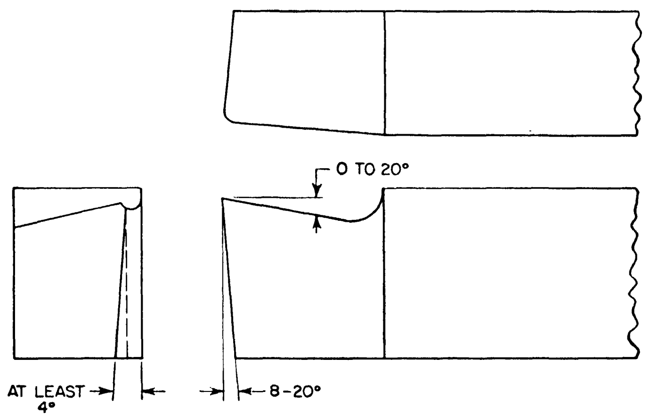


FIG. 9.11. Tool angles for turning aluminum or zinc die castings with a carbon-steel tool.

angle is not of vital importance, sometimes being 45 deg or more. The end-cutting angle is commonly 5 to 10 deg. The nose of the tool is rounded to a maximum of $\frac{1}{32}$-in. radius. Figure 9.12 shows the basic

turning tool recommended for machining such die castings. The angles given sometimes are varied, however, depending upon the rigidity of the machine.

For rough cuts, a starting speed of 250 sfpm is recommended. This speed may be increased if conditions permit. Many jobs run as fast as 400 sfpm. For finishing cuts, speeds of 400 sfpm and upward are recommended; speeds of 600 sfpm are not uncommon. Feeds vary from 0.005

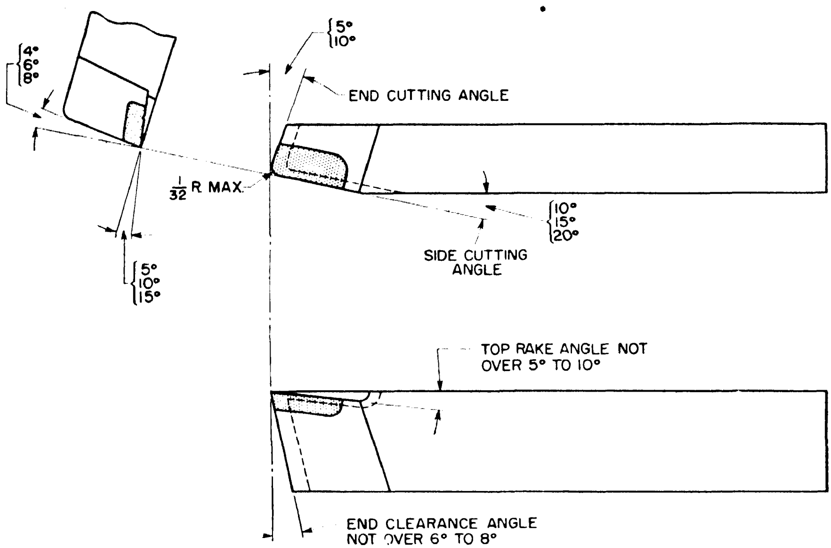


FIG. 9.12. Tool angles for turning aluminum or zinc die castings with a carbide-tipped tool. See Table 9.6, showing tool angles for turning other alloys.

to 0.0625 in. per revolution. In some cases, it is possible to rough and finish in one cut.

When tungsten-carbide tools are used for turning brass die castings, the tool angles shown in Table 9.6 have proved most satisfactory. These figures may be varied to accommodate prevailing conditions and are given merely as a reference or starting point for grinding. For roughing cuts on brass, a surface speed of 250 sfpm is recommended as a starting point; for finishing cuts, 350 sfpm and upward will produce the desired results. Speeds may be increased to as high as 1,000 sfpm under ideal conditions. Feeds may vary from 0.005 to 0.125 in. per revolution, depending upon the nature of the work and the amount of stock that has to be removed. As in other machining operations, high speeds and comparatively light cuts are recommended.

For turning magnesium with high-speed-steel tools, rake angles usually

are held between 0 and 15 deg. Carbide-tipped tools should have slightly smaller rake angles to provide more support for the cutting edge. Side- and end-cutting edge angles can be varied to fit requirements, but tools having side-cutting edge angles of above 40 deg are apt to cause chatter.

For roughing tools, the side relief angle is usually about 10 deg; the side rake angle, about 5 deg; the back rake angle, about 10 deg; the end relief angle, about 10 deg; the end-cutting edge angle, 15 deg; and the side-cutting edge angle, 15 to 25 deg. On finishing tools, the end-cutting edge angle is reduced to 5 deg, and the side cutting edge angle to 10 deg.

TABLE 9.6. TURNING OF DIE CASTINGS

Tool	Die-casting alloy		
	Zinc and aluminum	Brass	Magnesium
Type	Carbon steel, high-speed steel, or carbide-tipped tools.	High-speed steel or carbide-tipped tools.	High-speed steel or carbide-tipped tools.
Grind	For steel tools: 0- to 20-deg top rake, 8- to 20-deg end clearance. For carbide tools: 5- to 10-deg top rake, 4- to 8-deg end clearance.	For carbide tools: 0- to 8-deg back rake, 2- to 10-deg side rake, 4- to 8-deg side clearance.	For steel tools: 0- to 15-deg side-rake angle (usually about 5 deg) 0- to 15-deg-back-rake angle (usually about 10 deg), 10-deg-side-relief angle. Carbide tools should have slightly smaller rake.
Speed	Roughing cuts, 250 fpm; upwards as conditions permit. Finishing cuts, 400 fpm and upward.	Roughing cuts, 250 fpm; upwards as conditions permit. Finishing cuts, 300 fpm and upward.	Roughing cuts, 300 fpm and up; finishing cuts, 300 fpm and up. Speeds up to 5,000 fpm are possible with light cuts and feeds.
Feed	0.005 to 0.063 in./rev.	0.005 to 0.125 in./rev.	0.003 to 0.200 in./rev being used commercially.

Cutting speeds range from 300 to 5,000 sfpm for magnesium. For good finish, tool feeds should not be over 0.025 in. per revolution. In general, magnesium is turned at the maximum speed of the machine, with feed and depth of cut adjusted for individual jobs.

For boring, facing, and other lathe operations, rake and clearance angles usually are much the same as for the tools used in turning. As in other machining, light cuts and high speeds are recommended.

MILLING

Although milling operations on die castings are usually not necessary, they are entirely feasible. Cutters of high-speed steel are satisfactory, but cutters having inserted teeth of tungsten carbide are more efficient.

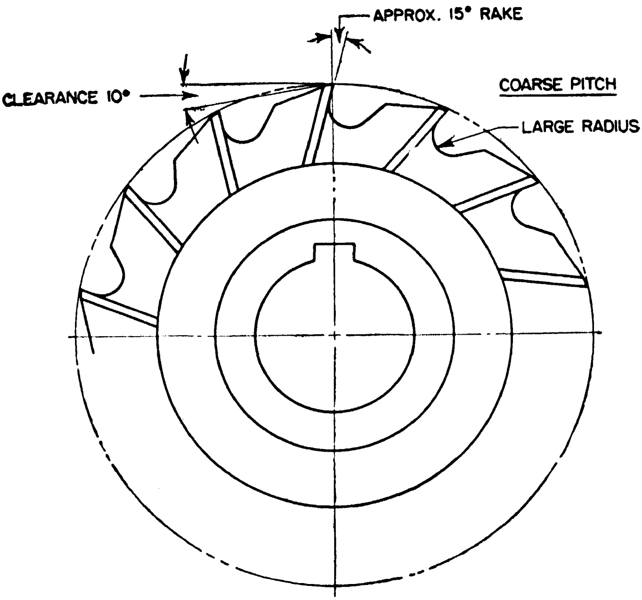


FIG. 9.13. Design of typical cutter for milling zinc and aluminum die castings.

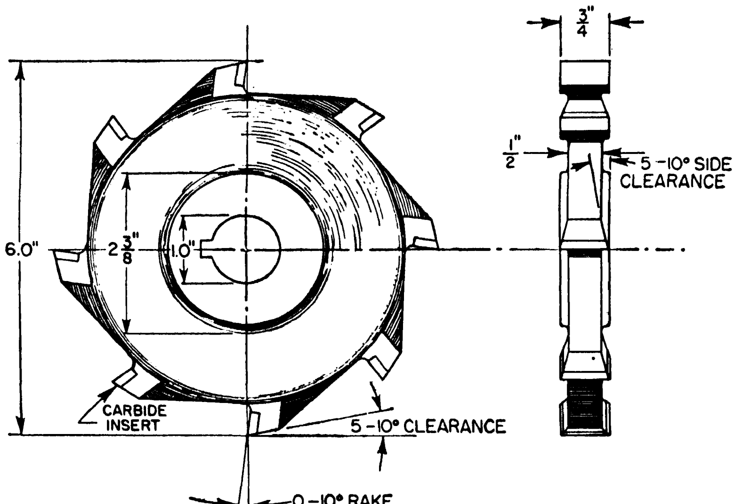


FIG. 9.14. Milling cutter for brass. Note the carbide inserts and large teeth.

TABLE 9.7. MILLING OF DIE CASTINGS

Cutter	Die-casting alloy		
	Zinc and aluminum	Brass	Magnesium
Type.......	Standard cutters if teeth are given extra clearance. Special cutters with coarse teeth are best.	Standard coarse-tooth cutters. High-speed steel or inserted tooth (tungsten carbide).	Side-cutting, slab, and straddle mills with ½ to ⅓ as many teeth as for steel. High-speed steel or tungsten carbide.
Grind.......	10- to 15-deg rake, 10-deg clearance. Large chip gash. Staggered teeth for deep slots.	0- to 10-deg rake, 5- to 10-deg clearance.	10- to 15-deg rake, 10-deg clearance. Helix angle of about 45 deg on helical slab mills.
Speed.......	....	600 to 2,000 fpm with tungsten carbide.	900 to 9,000 fpm. Usually at maximum speed of machine.
Feed........	....	0.008 to 0.015 in. chip load per tooth with tungsten-carbide cutters.	0.005 to 0.025 in. per tooth chip load with tungsten carbide. 0.005 to 0.015 in. per tooth for finishing.
Lubrication.	Required for aluminum alloys.	Usually required for fine finish.	Required for cooling and fine finish.

Stock cutters can be used, provided that the teeth are given an extra amount of clearance. About 10 deg is satisfactory for zinc, aluminum, and magnesium, although even more is used for special formed cutters; for brass, from 5 to 10 deg is satisfactory. An even or odd number of teeth can be used with similar results. Except for brass, a rake angle of 10 deg, as on most stock cutters, is satisfactory; but a 15-deg rake angle is preferred. A typical milling cutter for milling zinc and aluminum castings is illustrated in Fig. 9.13. Smaller rake angles from 0 to 10 deg are used for milling brass (Table 9.7 and Fig. 9.14).

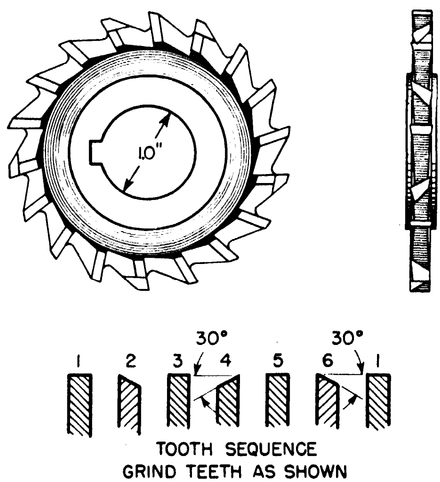


FIG. 9.15. Staggered-tooth milling cutter for milling deep slots in die castings. Alternate teeth are ground at opposite angles to obtain a free cutting action.

The use of cutters having staggered teeth (Fig. 9.15) is advantageous for deep slots, for they cut finer chips and give a better finish than those in which the chips are the width of the slot. A similar effect can be obtained with

nonstaggered cutters by nicking or chamfering the corners of alternate teeth.

Slab, slide-cutting, and straddle mills should be coarse-toothed, with one-half to one-third as many teeth as in milling cutters used for steel. Form milling can be done very easily with a form cutter such as is shown in Fig. 9.16. These cutters are usually form-relieved so that successive sharpening does not destroy the original form.

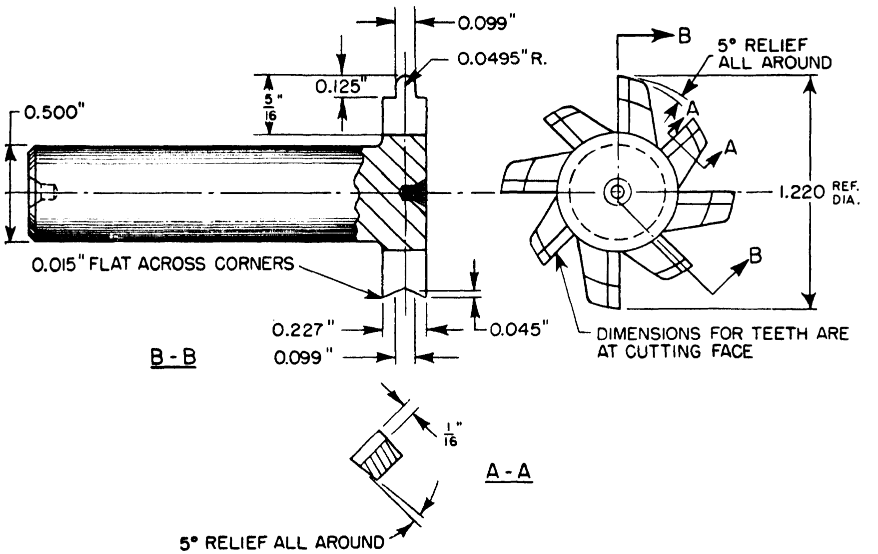


FIG. 9.16. Form-milling cutter for brass die castings. This cutter is operated at 4,500 rpm (1,500 sfpm). Chip load is 0.015 in. per tooth per revolution, and feed is 300 in./min.

A lubricant and coolant is sometimes necessary to hold close tolerance on brass and zinc and is very helpful in obtaining fine finishes. For aluminum, the use of a coolant is mandatory, as it is also for magnesium.

BROACHING AND SHAVING

Broaching or shaving operations are performed when it is necessary to hold exact sizes, or when a straightness condition is demanded that is not practical to obtain in the die casting. Since a taper is often required to get the casting out of the die, parallel surfaces cannot always be obtained on the casting. Shaving or broaching is used to remove this taper.

Broaches are made in many shapes and styles, one of which is illustrated in Fig. 9.17. The number of teeth and the chip clearances required are totally dependent upon the style of work that they must perform. Length, size of cut, and amount of stock that must be removed are the governing factors. Unless the user has had experience with broaches, it is advisable to obtain the advice of a reputable broach manufacturer. Standard broaching machines are well adapted for use on die castings, but often punch presses and other machines can readily be adapted to perform the necessary tasks.

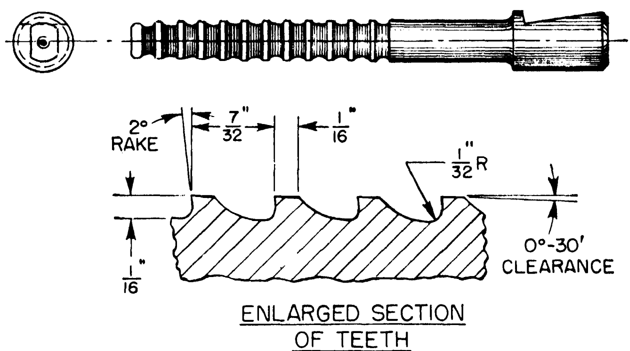


FIG. 9.17. Broach for finish-machining of brass die castings.

A shaving operation, in general, has reference to outside contours of castings. Very close tolerances can be obtained in this way, and a fine finish may be produced. A high-carbon, high-chrome type of steel is preferred for the shaving die because of its high wear-resisting properties. Die castings have a certain abrasive content that tends to dull cutting edges, and therefore this type of steel is preferred. Dies are relieved approximately $\frac{1}{8}$ in. below the cutting edges to allow clearance for the castings.

Shaving dies similar to those just described, but varying in contour to fit particular castings, are used to remove fins from castings. They are commonly made so that the opening has a straight land about $\frac{1}{8}$ in. wide to permit grinding on the face without changing the size; they are relieved below this land. Either a rubber cushion may be used to force the casting back through the shaving die or the casting may be permitted to fall through the hole.

If, in shaving in a punch press, shavings stick to the punch, they may mar succeeding castings. Difficulty on this score is avoided by covering the face of the casting with adhesive tape before shaving.

All sharpening operations are performed directly on the face of the die. A lubricant is not always necessary, but will help extend the die life and prevent metal build-up. An occasional application with a hand brush usually proves sufficient.

FILING

Filing is frequently used to remove burrs or light fins that cannot be removed economically in machine operations. Such is the case on large and cumbersome jobs and on parts having fins and flash in otherwise inaccessible places. It is chiefly helpful for short-run jobs. Filing operations can be reduced by good casting-die design, improved casting methods, and the effective use of well-made cleaning tools.

Any file suitable for rapid work on soft metal can be employed. Single-cut, relatively coarse teeth generally give a good finish and do not load easily. Burrs or rotary files of standard types are sometimes used to advantage (as in cleaning flash at the intersection of cored holes) where other cleaning tools would be awkward. Surface hardening and chrome plating increase abrasion resistance and are recommended for long tool life.

BENDING AND FORMING

Bending and forming of projecting parts of zinc-alloy castings that cannot be conveniently cast to the desired shape can be accomplished after casting. Mild heating may help to render the metal more ductile, but is seldom required; however, bending or forming should not be performed under 70°F.

Sometimes it is possible to make pairs of fittings, rights and lefts, by using a single-cavity die and appropriately bending some part of the casting. Further, where curving sections of hollow conduit must start and end in straight sections, coring is difficult and usually impractical; but it is not difficult to cast a straight tube and form the bend in it later. Also, parts of a piece which are cast in one plane may be bent or twisted into another. Finally, straight skirts and flanges may be shaped to hard-to-cast curved contours.

TUMBLING

A tumbling operation is frequently used to burr small castings. Light flash, ejector pins, and machining burrs can be removed by this method. Tumbling or deburring procedures vary considerably for different sizes,

weights, and shapes of workpieces. Experiments must be conducted to determine the preferred sizes of the load in the barrel and the abrasives and chemicals that may be used.

Generally, castings will be received in the tumbling department with oil and chips still on them from previous machining operations, so that a typical deburring operation will start with a cleaning or degreasing operation. After tumbling, a washing procedure is necessary to remove chemicals and abrasives. This is followed by a drying operation to make the parts suitable for handling and packing.

PUNCHING

Punching of holes and similar shearing operations can be performed on thin walls of die castings when such walls are supported by a lower die. Occasionally, such holes can be punched more rapidly than they can be drilled. Punching is usually done in combination with a trimming operation, however, and is therefore covered in detail in Chap. 10, Trimming of Die Castings.

GANG TOOLING

A mere description of the design of the tools used for machining and finishing die castings does not convey the basic idea behind all such tooling: *speed of operation.* Being a high-production operation, die casting requires high-production machining and trimming methods, and special and extensive tooling usually is justified. Gang tooling, especially for drill-press operations, clustering of machines, quick-acting jigs and fixtures, and semiautomatic or automatic cycling of machines, is standard practice in most die-casting plants. The use of specially built devices, such as that shown in Fig. 9.18 for milling the slots in the part sketched at the top of the illustration, is common; this particular fixture is so designed that the shafts of the cutters fit into a standard drill press.

Some idea of the speed of production constantly strived for can be obtained by considering the operations on three parts chosen at random from one die-casting plant: (1) an oil carburetor housing for home heating units, (2) a small generator end-bearing bracket, and (3) a valve rocker arm for an internal combustion engine. (1) The operations on the carburetor housing consist of turning it to height on a lathe; tapping 12 holes to various sizes; and facing three gasket seats. Production is at the rate of about 350 parts per hour. Part of the machining line for this job is shown in Fig. 9.19. (2) The operations on the generator and

bearing consist of broaching a center hole to a tolerance of ± 0.0005 in.; tapping two cored holes; and turning two diameters to a tolerance of ± 0.001 in. Eccentricity between the broached hole and the turned

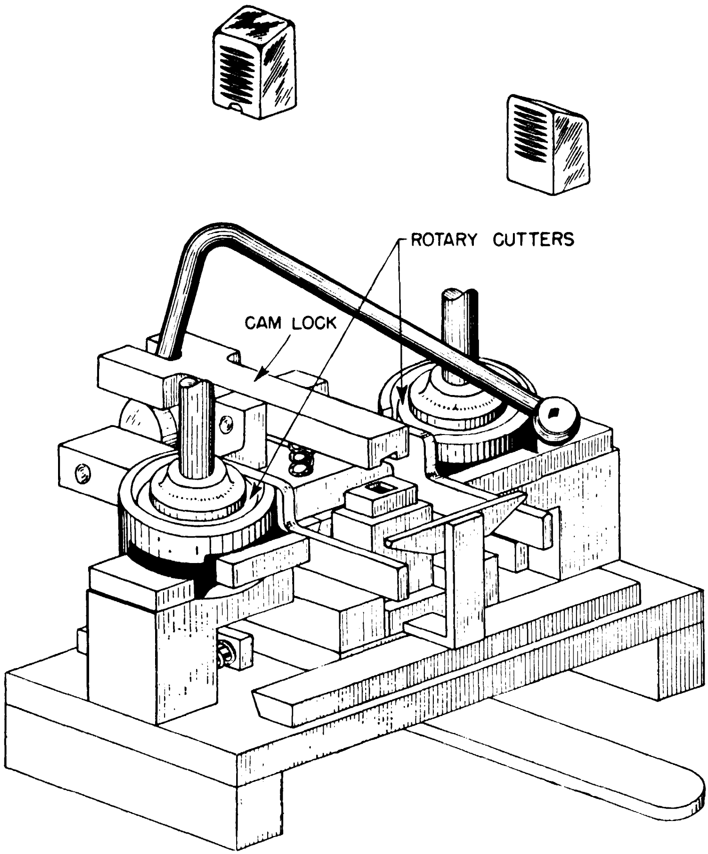


Fig. 9.18. Special tool for slotting the opening in the back and front of the die-cast part shown in the top drawing.

diameters must be held within ± 0.002 in. Production is at the rate of 400 parts per hour. (3) Finally, the operations on the valve rocker arm are as follows: trimming the part from the eight-impression gate on which it is cast on a broach which is equipped with side slides to open all holes. The casting then is routed to rotary burring machines, where all loose fins are removed, and on to an inspector at the end of the line. Production per hour is 2,800 parts.

To establish a functional approach that will ensure the success of machining operations is impossible in the space available in this text.

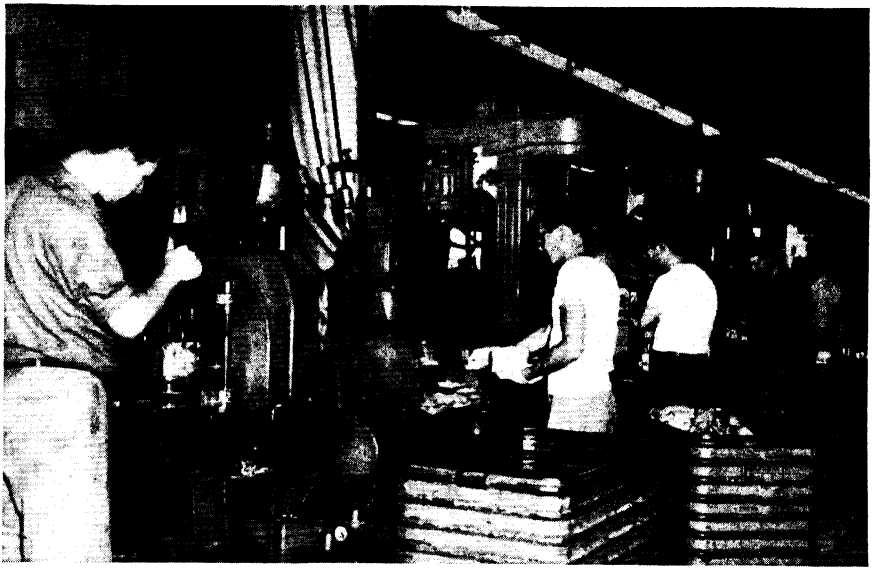


FIG. 9.19. A section of a machining line for turning, tapping, and facing an oil-burner carburetor housing.

The tooling is in the province of the toolmaker, and experience is the key to success. It might be mentioned, however, that small power tools are widely used, even for some operations on large parts.

CHAPTER 10

TRIMMING AND PIERCING OF DIE CASTINGS

Any die casting has a parting line at the point where the two halves of the casting die meet. This parting line is identified by a thin flash of metal that is formed when the molten alloy is forced under pressure between the mating die surfaces. Other parting lines may be caused by movable or stationary cores and slides. Also, small recesses are incorporated in some dies to permit trapped air to be forced out of the die impressions, and these recesses add the overhanging metal or flashes. All these flashes and parting lines, together with the gate, must be removed before the die casting is usable.

The early method of removing the flashes was to use a file or a scraper, or merely to break them away; but as quantity requirements grew, a mechanical method of trimming became necessary. The trimming die was devised for this purpose. It is an assembly consisting of a locating plate, on which the casting is placed, and a plate having an opening of the same shape as the casting. When the die plate is passed over the casting, it shears off the flashes projecting from the sides.

When trimming flash from a casting, it is general practice to attempt to trim against the body of the casting. This eliminates, to a great degree, the raising of burrs, which may be objectionable in handling or assembling. It also prevents "breakouts" (breaking of the adjacent wall) when gates and fins are exceptionally heavy or when flash must be punched from cast holes. If this direction of trimming cannot be used, however, it may be necessary to trim the flash in a direction away from the body of the casting.

The method of trimming plus ease of locating the part in the die control the type of die that must be used. The castings must be located so that no distortion is possible from the pressure of the trimming plate and so that no flashes are turned over onto other surfaces, thus requiring additional operations to remove them.

TYPES OF TRIMMING DIES

Trimming dies can be classified into four major types: the push-through trimming die, the overhead trimming die, the pressure-pad trimming die, and the combination trimming die.

The Push-through Trimming Die (Fig. 10.1). This trimming die is used for castings whose parting line or flash is so placed that the casting dimensions all flow from the parting line toward the casting center, *i.e.*, all dimensions on either side of the parting line are smaller than those at the parting line. This type of trimming die is usually the most economical one to build and should always be considered first if the casting can be easily placed in the trimming plate, if the casting will not be distorted while being pressed through the trimming plate, and if the casting can be protected against nicking and injury after it is pressed through the trimming die.

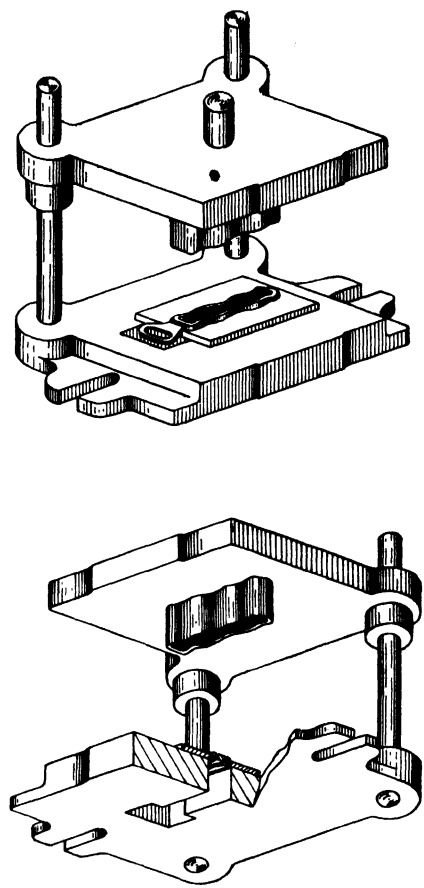


FIG. 10.1. Push-through trimming die. This type is usually the most economical to build and is used for small castings that have their largest dimensions on the parting line.

The push-through trimming die is composed of three main parts:

1. The *trimming plate,* made from a high-grade tool steel, into which the shape of the die-casting outline is machined. This plate is hardened and ground to a keen edge and then is doweled and fastened to a die base with screws.

2. A *pusher* or *punch,* which is made from a low-carbon steel if a simple or flat surface is to be contacted or pushed, or from a hardened high-carbon tool steel if the casting surface to be contacted or pushed against is irregular and complex. The pusher is aligned with the trimming plate and fastened either against the underside of the upper half of a die set or directly against the ram of a punch press. In most cases, a close fit or clearance between the pusher and the trimming plate is not necessary, accurate alignment between these members being of more importance.

3. The *die set* (Fig. 10.2), which is the means of aligning the two parts of the trimming die. The bottom or stationary plate of the die set is

bolted to the punch press; the top or movable plate is fastened to the ram of the punch press either with a stem or with bolts and is kept in alignment by hardened and ground guide pins and bushings. By locating and fastening the trimming plate with screws and dowels to the bottom of the die set, and the pusher or punch to the top of the die set, perfect alignment is maintained during the trimming operation. Of course, die sets are not always required, since the trimming plate and punch can be fastened directly to the base and ram, respectively, of the power press.

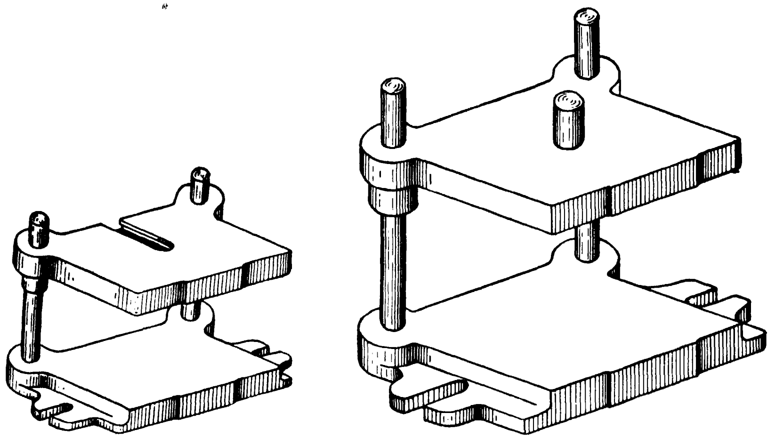


FIG. 10.2. Standard die sets for kick presses (left) and for power presses (right). Use of a die set usually is advisable since it ensures alignment of the punch and trim die.

Thus, on a well-aligned press, a die set may not be necessary, but for ease, economy, and assurance of proper alignment, the use of die sets is advisable.

When using this type of trimming die, the die casting is located by placing it into the trimming-plate spacing as far as the flash will permit. Power applied against the pusher by the ram of the press forces the casting through the trimming plate. The flash is pinched off between the edges of the pusher and the edges of the die. Speed of operation depends upon whether the shape of the casting permits ease of handling and locating, and also on the dexterity of the operator.

Push-through trimming is usually confined to the smaller die castings that will pass through the maximum opening in the bed or table of the power press.

The Overhead Trimming Die (Fig. 10.3). This type of trimming die is used for trimming die castings that have a parting line or flash which

can be trimmed against the casting body. The overhead trimming die requires (1) a locating block fastened to the lower half of the die set, (2) a trimming plate fastened to the top half of the die set, and (3) an ejector plate.

The locating block is usually made of a low-carbon steel; but when used on long-running jobs or when thin edges are unavoidable, a hardenable steel is used. This location block must be constructed so that no distortion of any part of the die casting is possible, so that the die casting can be easily located and removed, and so that all surfaces and openings to be cleaned are well supported. Whenever the recess is of intricate shape and/or would require considerable removal of metal, it can be more economically cast than it can be machined. This is done by pouring a molten zinc alloy into a prepared opening in the locating block and thus reproducing an exact recess with the casting as the pattern. The die casting is fastened into its proper position in the prepared location with screws, pins, or clamps, and molten zinc alloy is poured through an opening in the bottom of the location. Often a complete location or nest can be poured by preparing a casting within a metal enclosure, such as a box with removable sides.

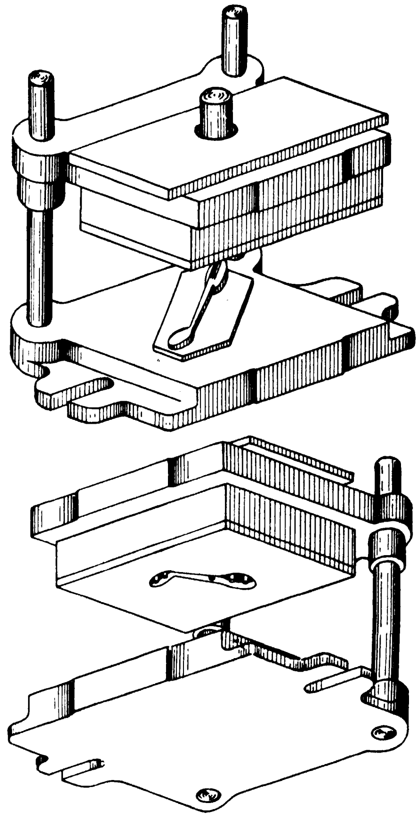


FIG. 10.3. Overhead trim die, which is recommended when the flash of the die casting can be trimmed against the casting body. The recess in the locating plate can be machined or cast.

Care must be exercised that all parts of the form are perfectly dry before the metal is poured, since moisture will cause it to splatter. It is also advisable to hold the temperature of the molten metal slightly above the slush stage, so that it will just pour from the ladle. Failure to do so may cause the die casting to burn fast to the poured mold, thus requiring considerable time to remove it and machine the form at the burned spots.

On long-running jobs it may be desirable to machine the entire recess from a solid steel block with a milling machine or a die-sinking machine. On the other hand, the nature of the die casting may not require a cavity; instead, its concave or internal shape may be located on a pedestal type of location. In any case, the only finish machining and fitting of the location that is necessary is at those points where pressure during the trimming operation may distort, mark, or bend the die casting; the balance of the location may be roughed-milled as clearance.

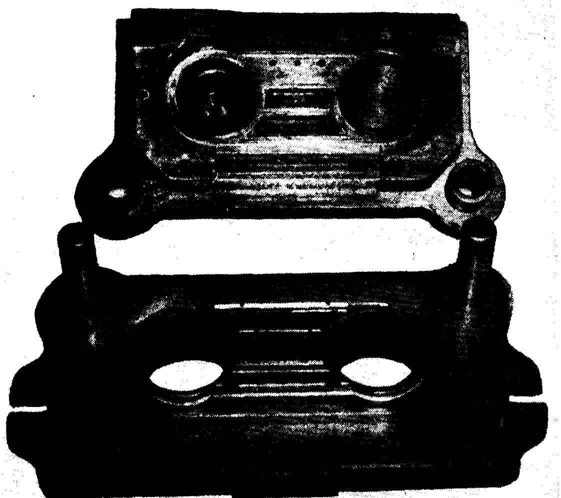


Fig. 10.4. Single type of overhead trim die and punch. The only finish machining that is necessary on such a die is at the trim line and at those locating points at which the casting may be distorted.

Two types of trimming plates are used for overhead trimming dies: (1) a plain, flat steel plate (Fig. 10.4), and (2) a bridge-type plate. The flat steel plate is employed when the nature of the casting is such that it will not stick to the punches (no ejection plate is necessary) or does not require any trimming in the region of the ram of the punch press or around the stem of the die set to which the trimming die is attached. On large trimming dies, the plate is made in sections to facilitate shaping the cavity to the die-casting outline and to minimize shrinkage and warpage in the hardening process. These sections are held in their proper relationship to one another and to the die casting with hardened dowel pins and screws. The die plates are made either from a water-hardening or an oil-hardening tool steel.

The bridge-type trimming plate (Fig. 10.5) is used on all small dies and on the large dies when ejection of the die casting is interfered with by the die-set stem or ram of the punch press. This type of trimming plate consists mainly of a plate that is separated from the die-set surface by narrow metal strips. A steel plate onto which ejector pins or blocks can be fastened then is placed between this trimming plate and the die surface.

An ejector plate is necessary with an overhead trimming die to eject the die casting from the trimming plate after the die casting has been trimmed. The ejector plate must function in such a manner that the die casting is not marred, bent, or distorted in any way. The conventional and most commonly used ejector plate is made from cold-rolled low-carbon steel. It is usually placed above the upper half of the die set, so that the ejector pins or blocks pass through the die set and beyond the trimming plate to engage the surface of the die casting. On the return stroke of the press, the ejector plate engages a pair of stationary bars or stems that force the plate containing the pins or bars against the casting, thus freeing it from the trimming plate.

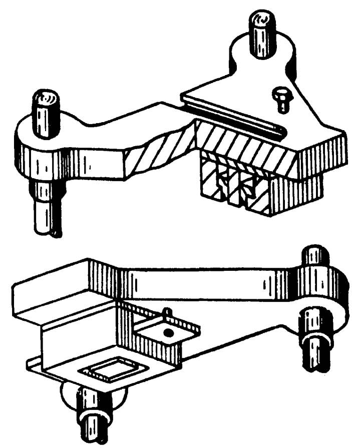


FIG. 10.5. Overhead trim die with bridge-type ejector plate. This type of trimming plate is used on all small dies and on large dies when the ram of the press or the stem of the die set interferes with ejection of the casting.

A bridge-type ejector plate is employed when the die casting must be ejected in the region of the clearance hole in the conventional ejector plate. To permit this type of ejection, the plate must function on the opposite side of the die-set upper half or opposite the conventional-type ejector plate, *i.e.*, in the space provided by the bridge-type trimming-die plate. This eliminates the necessity of the clearance hole for the die-set stem and provides the necessary metal to fasten ejector pins or blocks. Contact bars or studs that pass through the upper half of the die set and engage the same stationary bars that are used for the conventional-type ejector plate are provided on the outer edges of the ejector plate.

In the operation of the overhead trimming die, the die casting is placed on the locating plate. The press ram lowers the trimming plate, and the casting is trimmed. On the return stroke of the press, the trimming plate

is raised to its normal position, and the ejector plate engages stationary bars to eject the casting.

This type of trimming die should not be used when the casting may be marred, bent, or injured when it drops from the punch to the locating plate; heavy castings are usually in this category.

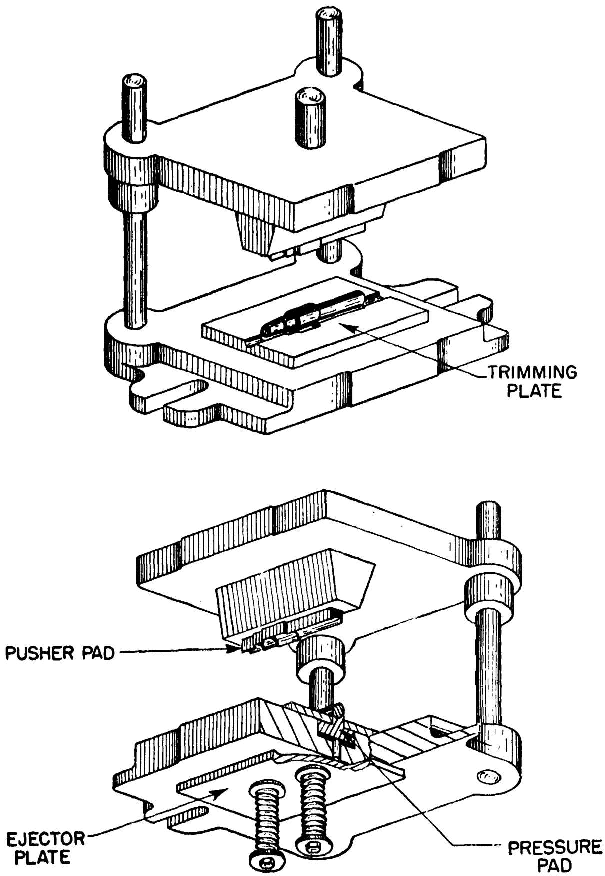


FIG. 10.6. Pressure-pad trim die. Although springs are shown as the pressure source, rubber pads or compressed air may be used to accomplish the same purpose.

The Pressure-pad Trimming Die (Fig. 10.6). A trimming die of this type is required when the die casting must be located and pressed through the trimming plate in the same direction. Die castings which have thin walls and no locating surface for overhead trimming dies, which are heavy, or which must be highly polished and plated are usually trimmed in a pressure-pad die.

This type of trimming die is composed of (1) a trimming plate; (2) a movable locating pressure pad; (3) an ejector or pressure plate; and (4) a pusher pad. The trimming plate is similar in construction to that used on an overhead trimming die, except that it is fastened to the lower half of the die set. It also keeps the locating pressure pad raised to the proper position for receiving the die casting.

The movable locating pressure pad is so called because it locates the die casting throughout the downward stroke of the press. The lower half

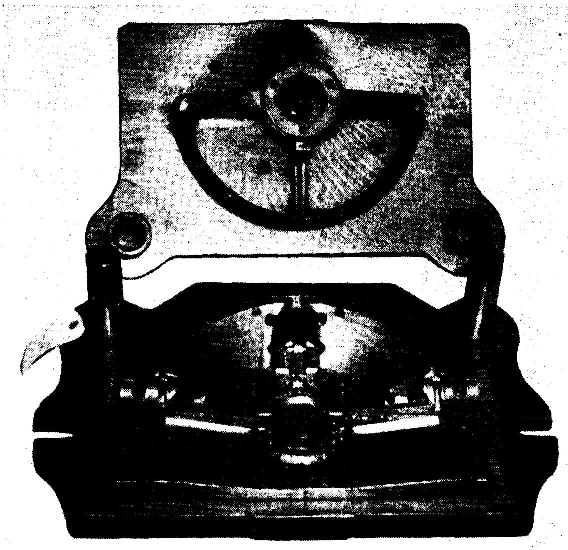


Fig. 10.7. Spring-pad trim die for trimming the horn rim of an automobile steering wheel. Pressure-pad dies are used when the casting must be located and passed through the trimming die in the same direction.

of the die set is recessed to accommodate the pressure pad and to provide the necessary space for the die casting to enter the trimming plate. Die pins in the lower half of the die set locate the pressure pad, and a machined shoulder permits it to be raised against the lower surface of the trimming plate to locate the die casting. Pressure applied by springs located between the pressure pad and the ejector or pressure plate maintains the normal position of the pressure pad and functions to eject the die casting on the upward stroke of the press. Some die-casting plants prefer to use rubber pads or compressed air in place of the conventional springs. In any case, the functioning of the die is identical.

The pusher pad, usually made of steel, is shaped to conform to the contour of the die casting opposite the locating side. It is attached to

the underside of the upper half of the die set and its function is to press the casting against the movable locating pressure pad to force both the casting and the pad into the trimming plate; it must pass within the trimming-plate opening. It is important that the pusher fit the die-casting contour to avoid marring or bending it; and on long-running jobs, hardening the pusher pad is advisable.

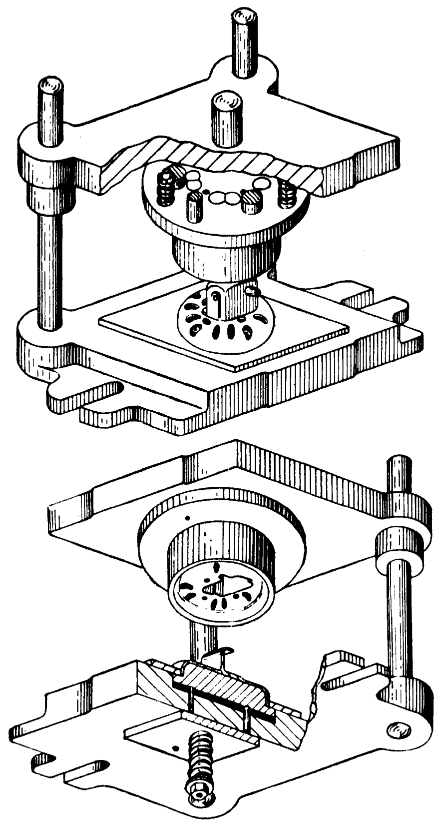


FIG. 10.8. Combination trim die, which incorporates the features of both the overhead and pressure-pad trimming dies. It is used when the casting cannot be cast with one common flash line.

The operation of this type of trimming die is as follows: The casting is located on the pressure pad when the press ram lowers the pusher against the casting; the springs under the pressure pad are compressed, thus pressing the pad and casting through the trimming-die plate. When the pusher is then raised to its normal position, the pressure pad also returns to its normal position, thus ejecting the casting from the trimming plate. The casting is then ready to be lifted from the location and placed in a container.

The Combination Trimming Die. Some die castings, because of their shape, cannot be cast with one common flash line. The casting die may be so constructed that the parting line is partly on one half and partly on the other half of the die, thus forming flashes that must be trimmed in opposite directions. To make this possible, the function and features of the two trimming dies—the overhead and pressure-pad types—are incorporated in a combination trimming die (Fig. 10.8). The die casting first is trimmed from the bottom upward as in the pressure-pad die. When the pressure pad arrives at the adjusted stops on the bottom half of the die set, the overhead trimming plate performs its function.

Multiple Trimming Dies. Trimming of more than one casting in the same die is often more economical than trimming each one individually.

Multiple trimming dies, such as shown in Fig. 10.9, may be used to trim two or more impressions of identical castings or two or more different castings having a common parting line. They are used (1) when a single trimming die is too slow to meet production demands; (2) to eliminate extra handling; (3) to simplify location in the trimming die; or (4) for economy of operation. The dies can be of any of the previously described types or can be combinations of push-through and overhead trimming dies, of push-through and pressure-pad trimming dies, or of overhead and pressure-pad trimming dies. The kind of casting determines the combination; for example, two identical castings to be trimmed overhead and two mating castings that must be trimmed with a pressure-pad die would require a four-impression trimming die, one-half of which would be of the overhead type and one-half of which would be of the pressure-pad type. The size and number of impressions are limited only by the capacity of available equipment.

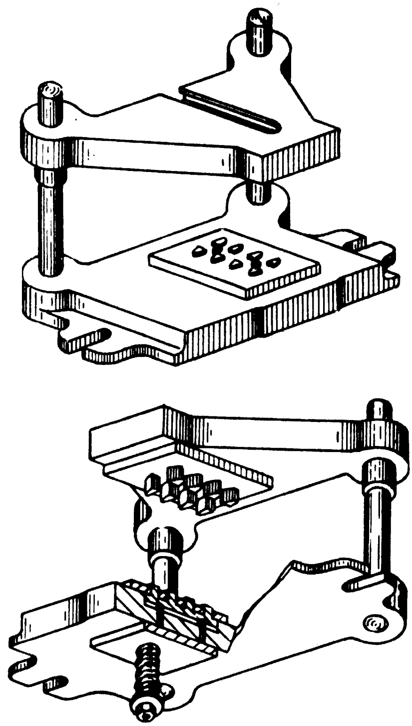


Fig. 10.9. Multiple trimming die, which often is used to trim a number of castings simultaneously. The number and size of impressions are limited only by the size of presses and die sets that are available.

Multiple trimming dies are adapted to the same types of presses as single trimming dies. The construction of the dies is identical to the single dies except that ejection is usually accomplished with one large plate for all impressions, and the pressure pads are controlled by one pressure unit.

SPECIAL TRIMMING FIXTURES AND ATTACHMENTS

When castings need additional cleaning operations other than those possible with one of the trimming dies previously described, hand-operated side slides can be attached to the trimming die as shown in Fig. 10.10. This illustration shows a simple type of side slide consisting of a round bar sliding through a hole in a block that is fastened to the lower

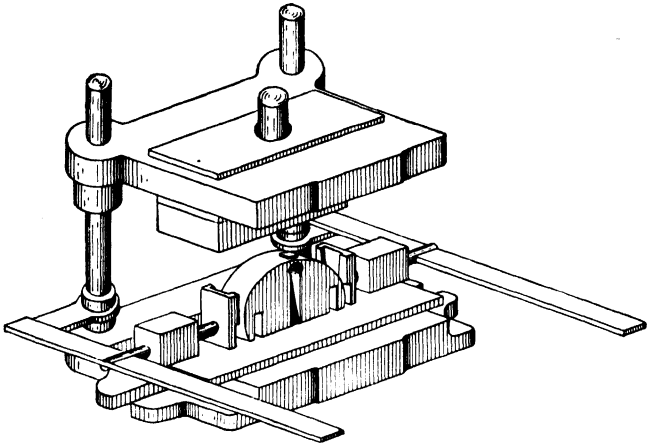


FIG. 10.10. Trim die with hand-operated side punches. Such side punches also may be actuated by hydraulic or pneumatic cylinders if conditions so warrant.

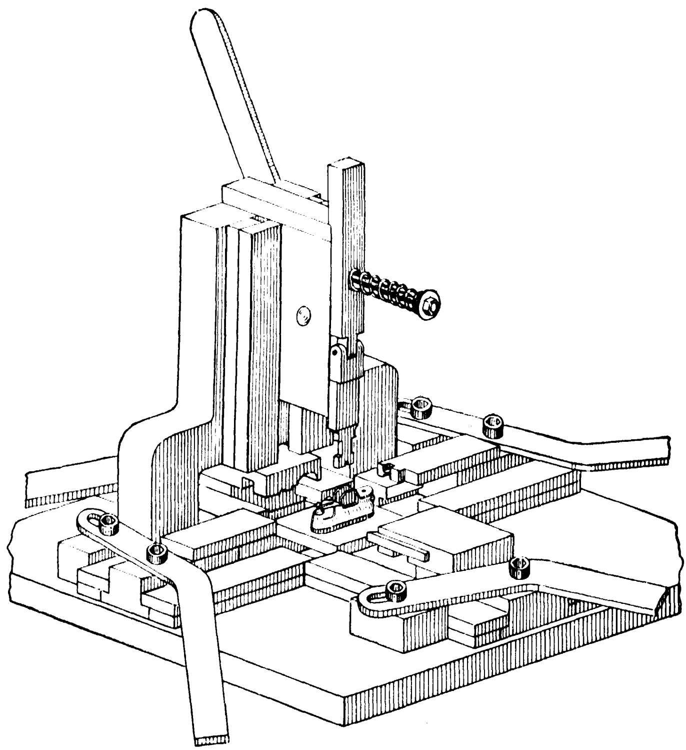


FIG. 10.11. Hand-operated bench fixtures for removing light fins from die-cast parts. When size and power requirements are heavier, kick or power presses are utilized.

half of the trimming-die set. The trimming plate or punch is fastened to the locating end of the round bar and is engaged with the casting by means of a lever that is actuated by the press operator. When the effort required to move the slide is above normal, a cam or compounded-lever mechanism can be incorporated in the design. If this is not feasible or will not bring the effort expended by the operator within reason, a hydraulic or pneumatic cylinder can be attached to the slide.

FIG. 10.12. Special hydraulically operated press for trimming the gate and flash from a cluster of small die castings. Presses with a long stroke are necessary for trimming operations so that the castings can be easily inserted and removed from the die.

Most trimming fixtures require sturdier slides than those shown in Fig. 10.10, in which case the punches are attached to rails that slide between locating blocks, as illustrated in Fig. 10.11. In this fixture, four slides move in a horizontal direction, and one slide in a vertical direction. When multiple-slide fixtures of this type are employed, several important factors must be considered and provided for. For example, the vertical slide must be held in the upward position while the operator is loading or unloading the fixture; the die casting must be located to avoid injury to the operator's hands; and provision must be made to keep the slides free from flash and chips. Also, the levers must be arranged to be operated in proper sequence to avoid injury to die castings or trimming-die edges; motions should be combined to require as few levers as possible.

TRIMMING PRESSES

Standard, motor-driven punch presses are usually suited for trimming die castings; however, those with a long ram stroke and adjustable knee are preferable. For some castings, an inclined-type press is very efficient since it allows the die casting to fall away from the operator through the back of the press after it has been ejected from the trimming die. Some trimming is performed in hydraulically operated presses such as shown in Fig. 10.12, some in foot or kick presses, and some in arbor

presses. In any type of press, it is necessary to provide adequate safety devices to guard the operator from hand injuries. It must be remembered that the operator has to locate and remove the casting and that some presses can be operated at the rate of 600 strokes/hr on larger castings and 1,500 strokes/hr on small castings.

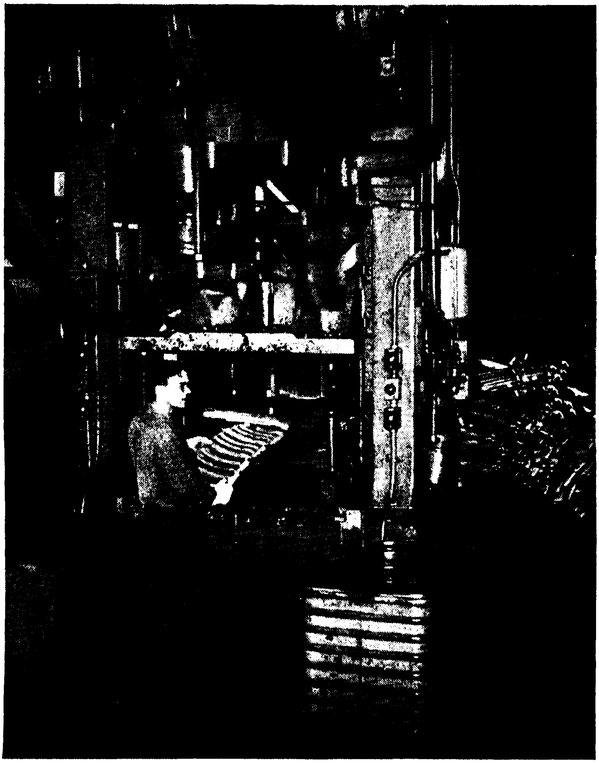


FIG. 10.13. Power-operated trimming press for automotive grille parts.

For removing light fins, small hand presses or special tools operated by a rack and pinion are usually used. Kick presses are also employed for such operations. For large castings, power presses are used extensively (Fig. 10.13). In all cases, the time required per piece is chiefly that needed to insert and remove the casting, the stroke of the press being almost instantaneous.

PUNCHING AND PIERCING OPERATIONS

Frequently it is more economical to pierce holes and openings in a die-cast part than to cast them. This is especially true of thin sections of die castings. The combined cost of providing cores in the casting die and providing cleaning punches in the trimming die to remove the flash

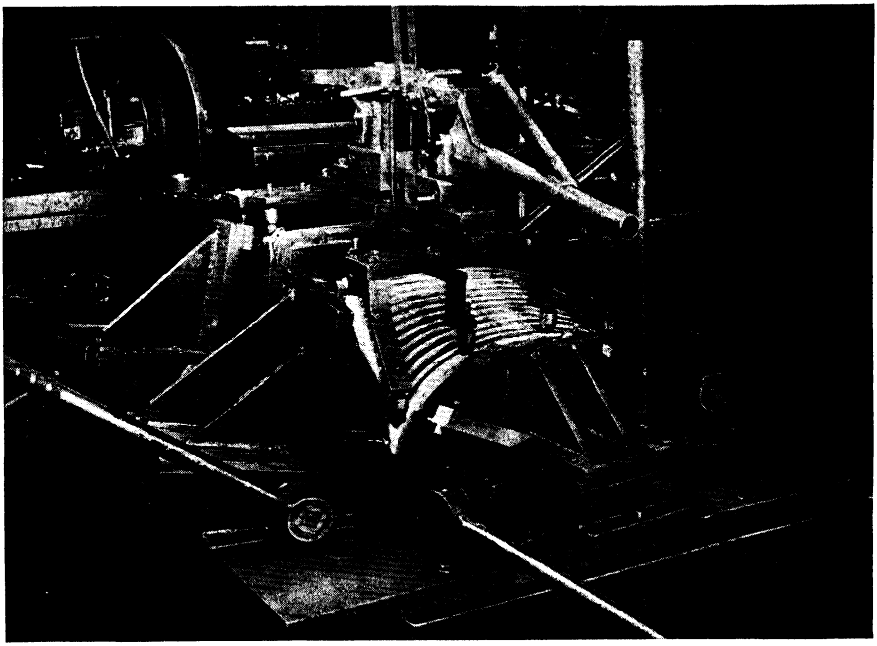


FIG. 10.14. Hand-operated piercing die for piercing holes in a die-cast zinc automotive grille.

from the hole or opening makes it more economical to pierce the hole or opening in piercing dies such as are shown in Figs. 10.14 and 10.15. The thickness of metal and the diameter of holes that can be pierced are governed by the same standards as for sheet metals. Standards tables are obtainable from any of the metalworking handbooks.

In addition, cored holes usually contain a casting flash or fin that is conveniently removed by a punching operation. If fins are to be punched from such holes, it is sometimes an advantage to use a sufficient taper in the hole to permit using the hole itself as the die. By punching the fin toward the large end of the hole, objectionable burrs can often be eliminated. A lubricant should always be used, either on the punch or the casting, when aluminum-alloy die castings are punched.

STEEL FOR TRIMMING DIES

The type of steel used for trimming dies varies widely with different die-casting companies and often even within the same company, depending upon the particular job to be done. Very often a single trimming die is made up of a number of different materials. Generally, the steels used fall into the following types:

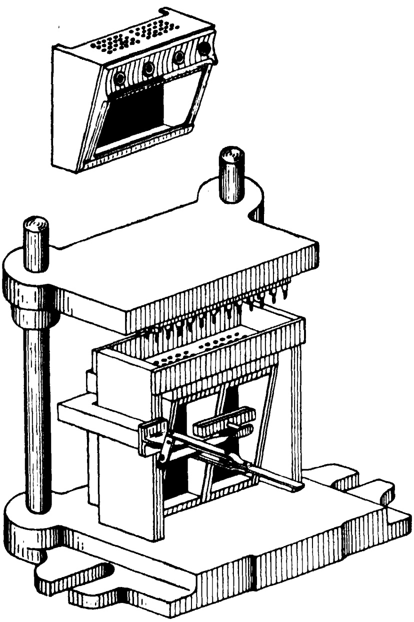


FIG. 10.15. Piercing die for power-operated press showing the part in position after the operation has been completed. It frequently is more economical to pierce small holes than to cast them.

1. Nondeforming oil-hardening steels such as a high-carbon-manganese tool steel (carbon, 0.9 per cent; silicon, 0.3 per cent; manganese, 1.5 per cent; and chromium, 0.2 per cent). This type of steel is used when a fully hardened die is required with a hard (60 Rockwell C) cutting edge.

2. Nondeforming air- or oil-hardening steel such as a high-carbon high-chromium steel (carbon, 1.5 to 2.0 per cent; chromium, 10 to 13 per cent). This type of steel is used when good wear resistance and a hard cutting edge are important factors.

3. Flame-hardening steel, such as high-carbon tool steel (carbon, 1.0 to 1.2 per cent). These steels are used for very complex dies that are hazardous to heat-treat or that may require some adjustment during their service life. They are flame-hardened at the cutting edge to a hardness of about 60 Rockwell C.

4. Soft steel, such as SAE 1020, and, in some cases, hubbing steel, is used for nests. Cast nests of zinc are also used occasionally, as previously mentioned.

CHAPTER 11

INSPECTION OF DIE CASTINGS

Inspection in the die-casting industry is essentially the same as in all other basic manufacturing industries. It consists of visual, dimensional, and physical checks to ensure that manufacturing specifications are being met. These tests are not always of equal importance since the end use of the part will govern whether appearance, dimensional accuracy, or physical properties are the most necessary.

The inspection department represents the customer in its efforts to maintain the standards of quality that are required in the product. The specifications for each individual part are arrived at through conferences between the die-casting sales engineer and the engineers and buyers representing the customer. The end use of the product is discussed, and the type of surface finish, important dimensions, and other data are agreed upon when each job is accepted. After samples have been approved and the part goes into production, it becomes the duty of the inspection department to make sure that the specifications are met.

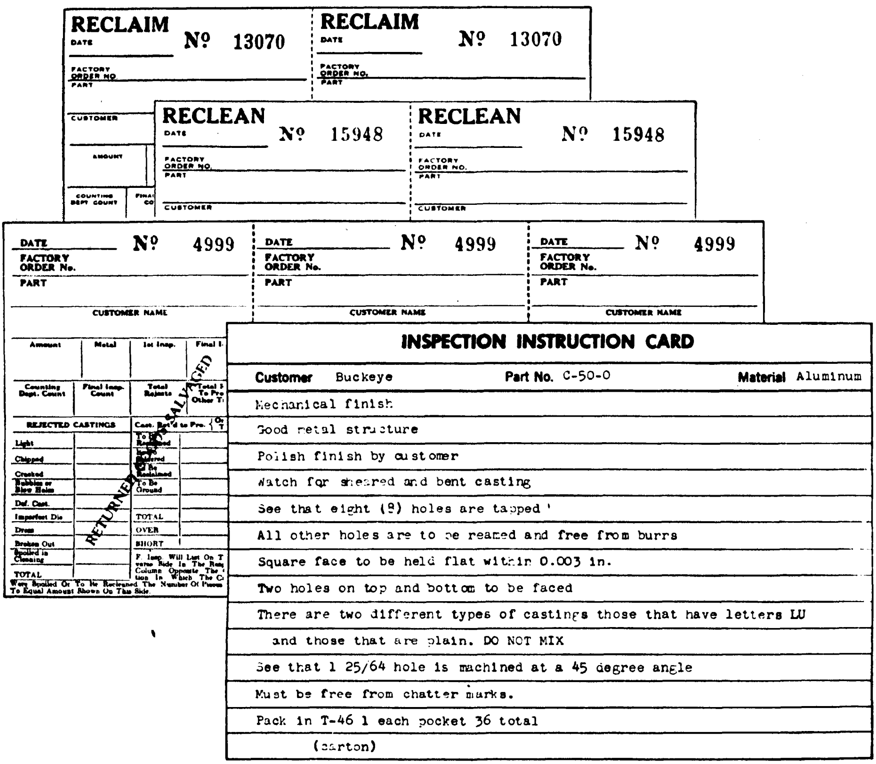
At the same time, the inspection department works in the interest of its own company in making sure that practical common sense is applied to the interpretation of the specifications. For instance, suppose that a certain cast hole appears on the blueprint as 0.230 $\pm$0.005 in. diameter with a notation that the customer is going to ream it to 0.250 $\pm$0.001 in. diameter. A dimensional check reveals that the hole measures 0.236 in., or 0.001 in. over the high limit. It would be poor judgment to reject a quantity of castings for such a defect since it is obvious that ample stock remains for reaming. On the other hand, the inspection department must not be too ready to accept material that is outside of specification limits; such decisions are generally reserved for the chief inspector.

Sometimes when there is a question as to whether a deviation may cause the customer difficulty, especially when the machining or fabrication details are not known, the inspection department may contact the customer and request a deviation. Granting of a deviation does not relieve the die caster of making the necessary corrections as soon as possible. However, it is against the interests of both the user and the producer of die castings to try to attain unnecessary perfection, since

the resulting high costs would reflect in higher prices to the customer and would make it difficult for the producer to compete for business.

FIRST INSPECTION

In die casting it is general practice to inspect all parts twice. First inspection, or "hot" inspection, as it is sometimes called, takes place as



RECLAIM DATE Nº 13070 FACTORY ORDER NO. PART CUSTOMER AMOUNT COUNTING DEPT. COUNT

RECLAIM DATE Nº 13070 FACTORY ORDER NO. PART

RECLEAN DATE Nº 15948 FACTORY ORDER NO. PART CUSTOMER

RECLEAN DATE Nº 15948 FACTORY ORDER NO. PART CUSTOMER

DATE Nº 4999 FACTORY ORDER No. PART CUSTOMER NAME

DATE Nº 4999 FACTORY ORDER No. PART CUSTOMER NAME

DATE Nº 4999 FACTORY ORDER No. PART CUSTOMER NAME

RETURNED GOODS SALVAGED

INSPECTION INSTRUCTION CARD

Customer Buckeye	Part No. C-50-0	Material Aluminum
Mechanical finish		
Good metal structure		
Polish finish by customer		
Watch for sheared and bent casting		
See that eight (8) holes are tapped		
All other holes are to be reamed and free from burrs		
Square face to be held flat within 0.003 in.		
Two holes on top and bottom to be faced		
There are two different types of castings those that have letters LU		
and those that are plain. DO NOT MIX		
See that 1 25/64 hole is machined at a 45 degree angle		
Must be free from chatter marks.		
Pack in T-46 1 each pocket 36 total		
(carton)		

FIG. 11.1. Some of the forms that may be used in the course of inspection: reclaim report, reclean report, return-goods salvage report, and inspection instruction card.

the gates of castings are taken from the casting machine and passed by chute or conveyor to the inspection station. The inspector picks up the casting, which is still attached to the gate, and inspects it for finish, run marks, porosity, poor fill, cold shuts, depressed or raised ejector marks, broken cores, distortion, cracks, and the like. Good castings are broken from the gate and placed in containers for transfer to the trimming and machining departments. Defective castings are marked at the point of

defect and are placed, along with broken-off gates, in a scrap truck to be sent to the alloying department for remelting.

The inspector counts the castings and posts the quantity of good and scrap parts on a casting-machine production card. (A few typical inspection forms are shown in Fig. 11.1.)

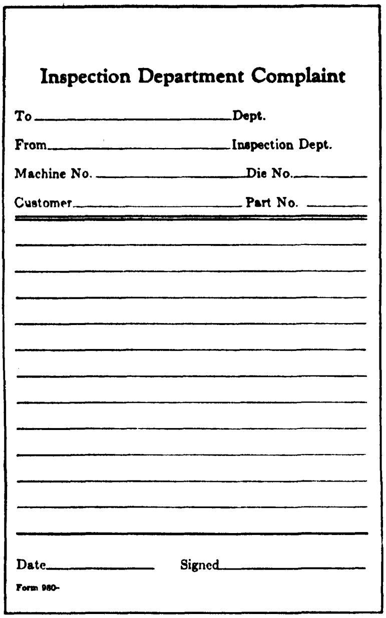
The first inspector who does his job well can contribute greatly to the efficient operation of the casting department and to the reduction of

FIG. 11.2. Typical parts that must be inspected closely for smoothness of surface and accuracy of coring. *A*, Aluminum magneto flywheel for small outboard motor; *B*, aluminum flywheel and fan for gasoline washing-machine motor; *C*, aluminum fan for 5-hp electric motor; *D*, magnesium vacuum-cleaner fan; *E* and *G*, blower halves for motion-picture projector; *F*, aluminum power-tool fan; and *H*, aluminum vacuum-cleaner fan.

rejects. In an operation that is necessarily fast in order to keep up with machine production, his training and experience gained over a period of time will enable him to spot changes in operating conditions that affect the quality of the castings. He knows that the first castings produced from a die that is not up to regular operating temperature will have a higher percentage of rejects due to run marks, porosity, and cracks. He watches this carefully, and after a reasonable length of time, which may be from a few minutes to half an hour, will advise the operator or the casting or inspection supervisor if the castings are not coming out properly.

He makes it a practice periodically to take the last casting coming from a machine and look it over carefully for broken or incorrectly located cores, drag marks, and surface imperfections, particularly on

parts such as those illustrated in Fig. 11.2 that must have a smooth finish. He will note, on parts that must have a good surface finish, when the first indication of solder or roughness shows up and will ask for correction of this condition at once. He will be aware of changes in metal temperature when new metal is added to the holding furnace. If the metal becomes too hot it will show up in increased porosity, heat spots, solder, and possibly blowups in cored holes or heavy sections; if the metal is too cold, the surface of the castings will show run marks and cold shuts.



Inspection Department Complaint

To ____________ Dept.

From ____________ Inspection Dept.

Machine No. ____________ Die No. ______

Customer ____________ Part No. ______

Date ________ Signed ____________

Form 980-

FIG. 11.3. Typical inspection complaint form used by inspection supervisor to report imperfections in surface detail, dimensional accuracy, and other faults to the casting supervisor.

A polisher is usually assigned to the first inspection department for the purpose of checking the finishes on castings that require plating or painting. His duties consist of gathering samples hourly from each machine producing this type of part and of trimming, polishing, and buffing them to make sure that they are up to standard. Frequently, it is difficult to determine by visual check alone if slight surface defects will come out in this treatment, but the polisher can determine this very quickly. When he finds conditions such as slight cave-ins or porosity at the parting line, heat spots, cold shuts, or other defects that are not cleaned up in the operation, he reports it at once to the inspection supervisor. The supervisor reports this verbally and by means of an *inspection complaint form* (Fig. 11.3) to the casting supervisor, who takes steps at once to remedy the condition.

Dimensional Checks. Part of the first inspection operation is dimensional checking. This is done by a checker who makes periodic rounds of a certain group of machines and, after a preliminary visual inspection, takes a sample from each machine to the checking room for a dimensional check. This inspector is concerned mainly with variable dimensions, which are those controlled by movable parts of the die. He also checks cores for depth and diameter at least once each day. To do this work the checking department must be equipped with surface

plates, height and depth vernier gages, micrometers, calipers, V blocks, parallel bars, centers, and various other measuring instruments. Special gages must be provided for checking important dimensions on specific jobs that must be checked often. This may be a gage with a number of sliding plugs to check the size and relative location of several holes, or it may be a number of gages specifically designed for checking one part (Fig. 11.4).

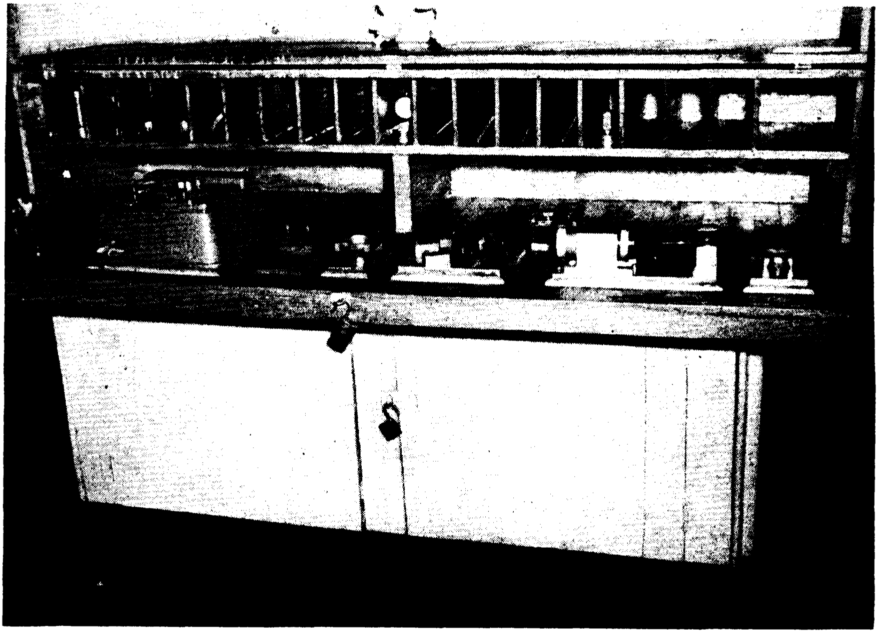


FIG. 11.4. Special inspection bench for checking various dimensions of one high-production casting. Custom-built gages for intricate parts produced in large numbers are not unusual.

In case there are dimensional defects, the checker also fills out an inspection complaint and gives it to the inspection foreman along with a marked casting. A copy of the complaint is attached to the blueprint for follow-up. The inspection foreman decides whether the defect is serious enough to require immediate correction, but in case of doubt will refer the matter to the chief inspector for his decision. Sometimes, after discussion with the casting foreman, it is found that the die must be dismounted and reset to correct the conditions. In that case, it may be more economical to consider a salvaging operation on the castings to keep the die in production until it is more convenient to repair it.

For example, suppose that a certain part has a balance of 1,000 pieces

to run when a core breaks and that the die dismounting and resetting operation will cost about \$50 to \$60—not including about 6 hr of lost production.

A salvage drilling operation can be performed for about 1 cent a piece plus about \$10 for a simple drilling plate with a bushing. Obviously, the cost of salvage at about \$20 is more economical than a die-repair job that would cost over \$50. The cost of replacing the core is not considered since that will have to be done anyway when the 1,000 pieces are completed and the die comes out of production.

When considering salvage operations, the cost of the operation, the probable scrap loss, and the effect on the quality of the part should be evaluated. This should be compared with the cost of lost production (since a die-casting plant can make money only when the casting machines are producing), the cost of die dismounting and resetting, and the effect on the delivery schedule. Only when the salvage operation shows a distinct advantage should it be performed.

At the end of a production run it is the duty of the first inspection department to make a thorough check on the parts produced by a die to see what corrections or improvements must be made in preparation for the next run. This is done by the dimensional checker, who receives one or two of the last gates from the casting department and checks the various dimensions. Particular attention is paid to cored-hole sizes, ejector-pin marks, important dimensions, slides, and drags. An inspection complaint form is written out and reviewed by the inspection foreman. This form is then attached to a die-repair order form, which is made out by the casting supervisor and delivered with a marked casting to the die-repair department. A copy of the inspection complaint is attached to the inspection blueprint and held for follow-up when the die is returned to production. Careful attention to this detail ensures that the necessary work will be done and that the die will again be in first-class condition when needed.

Internal Inspection. Nondestructive internal checks are generally the responsibility of the first inspection department. Any one of four techniques is commonly employed, namely, X-ray inspection, fluoroscopic examination, photo-roentgen inspection, or Zyglo examination.

X-ray or radiographic inspection as a rule is used as a spot check for soundness in sections not readily seen in the fluoroscope. It is also used to obtain a permanent record for study of the effect of various gate changes. Of course, there are some jobs on which the customer specifies, and pays for, 100 per cent X-ray inspection, but these are very few.

X rays are electromagnetic types of waves used in industry to pene-

trate opaque materials and obtain a permanent record on a sensitized film. The short wavelengths of radiant energy have become a useful tool for the inspection of the interior of metals and other materials. When these rays pass through materials of nonuniform structure contain-

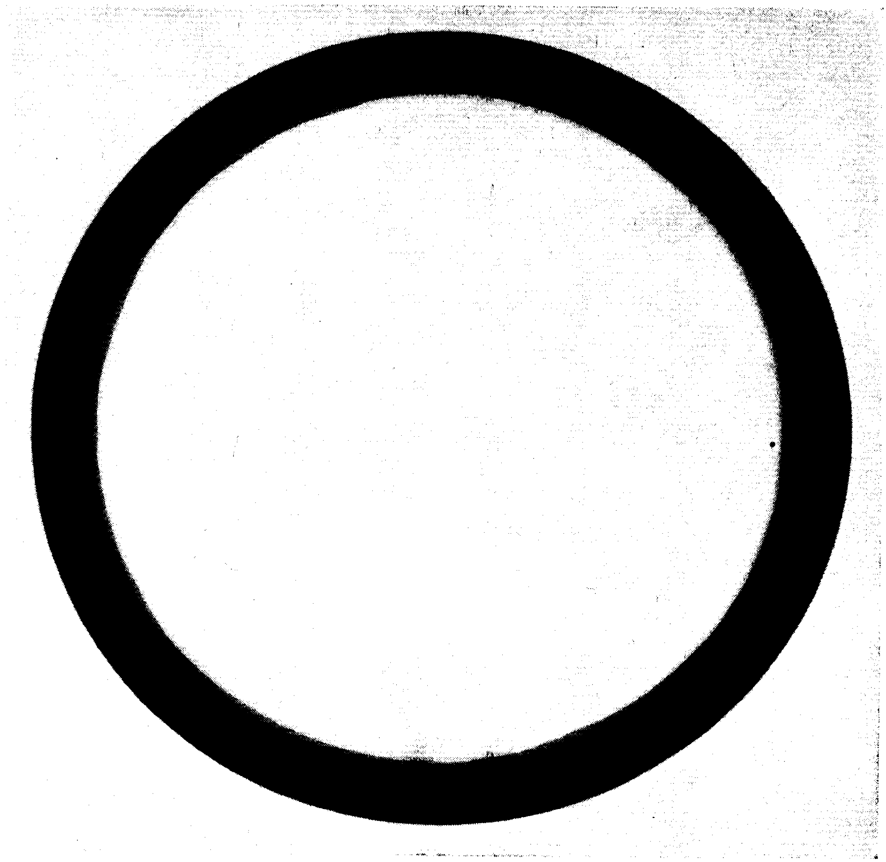


FIG. 11.5*a*. X-ray photographs of good die-cast ring.

ing defects such as voids, porosity, or cracks, they are absorbed to a lesser extent than the rays passing through sound material. This results in light and dark areas on the light-sensitized film, the dark sections representing that part of the material having a lower density. Reproductions of X rays of four castings—two sound and two unsound—are shown in Fig. 11.5.

Radiographic examination is an extremely important adjunct to the die-casting process, not only for indicating the internal condition of a casting but also for determining the right casting conditions to produce the best type of castings. X rays taken of die castings at the beginning

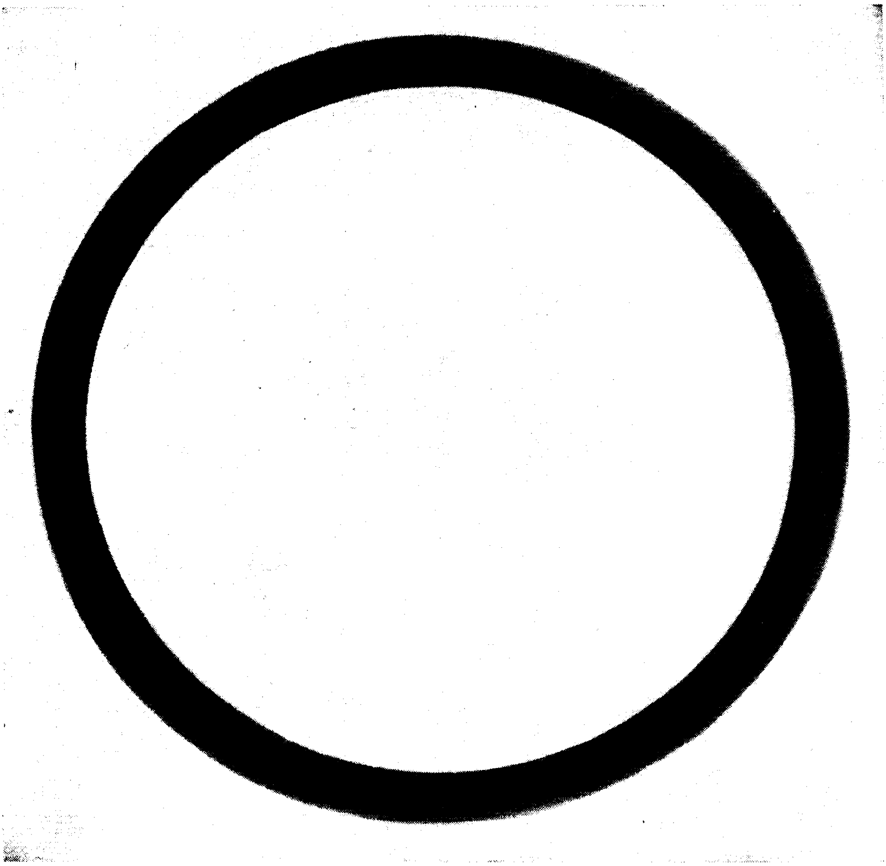


FIG. 11.5*b*. X ray of porous die-cast ring. Dark areas on the X-ray negative indicate porosity and blowholes, which are shown here as light areas.

or the breaking in of a new die can greatly aid the die caster in determining the effect of a gate change, the extent of venting required, the effect of metal and die temperature and pressures, and other operating conditions. Such radiographs will show the results of each successive change in casting conditions and thus aid in arriving at the maximum soundness and best surface finish on the castings.

For inspection of die castings, the equipment usually is of the direct-

radiographic type, rated at about 140 kv. It is contained in an enclosed steel cabinet and shielded with an adequate thickness of lead sheeting for protection against stray radiation. The cabinet contains the X-ray

FIG. 11.5c. X ray of porous motor housing.

tube, which is positioned and supported so that it can be operated within an arc of about 60 deg and through a height range of from 20 to 40 in. The 140-kv unit can penetrate a thickness of 4 in. of aluminum, but only about $\frac{5}{16}$ in. of zinc.

Fluoroscopic examination is used when a more rapid, economical inspection is required. Fluoroscopic equipment (Fig. 11.6) permits visual inspection of a number of castings at one time, the number being de-

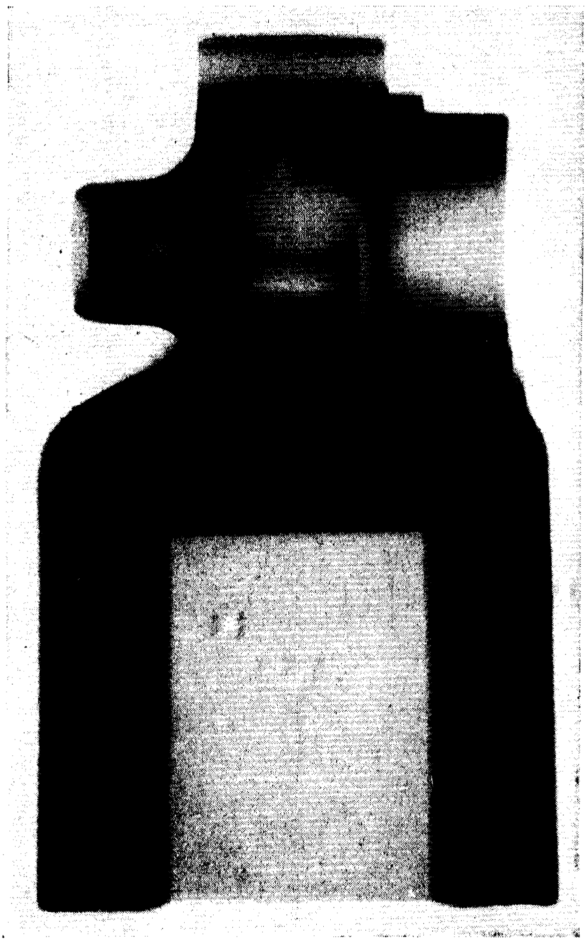


FIG. 11.5*d*. X ray of sound motor housing.

pendent upon the size of the casting. While such equipment does not have the sensitivity of radiographic-film inspection, it serves adequately in many cases in detecting internal unsoundness—and at a much lower cost than radiographic examination; a trained operator can readily detect porosity if the castings in question are not too heavy.

The equipment is of necessity operated in darkened rooms. For the

general run of light alloy die castings, the fluoroscopic equipment is capable of an inspection sensitivity of from 3 to 6 per cent, as against a possible ½ per cent sensitivity for radiography. There are, however, a number of variable factors which control perception of the eye on the fluoroscopic screen. It is therefore difficult to state the exact inspection sensitivity for any material unless all the factors that control the image are known. The most important factors affecting accuracy of

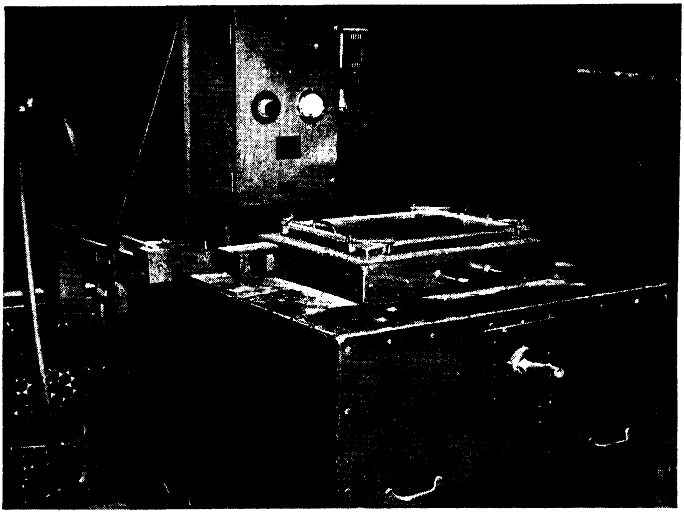


FIG. 11.6. Fluoroscopic setup for inspection of die castings. The advantage of this type of inspection, compared with X-ray inspection, is that it is much cheaper and faster. Sensitivity is not so good, however.

fluoroscopic inspection are the operator's vision; the composition and the size, shape, and section thickness of the casting; and the number of pieces to be inspected in a given period.

Photoradiographic inspection, using a photo-roentgen unit (Fig. 11.7), is an important inspection technique for large-scale radiography of die castings. The photoradiograph is actually a fluoroscope to which is attached a camera that photographs the image of the casting on a fluorescent screen, reducing it to a 4- by 5-in. picture. This unit was first used by the Army Medical Department for making chest X rays, was adapted for industrial use in 1942, and has since been successfully used for inspection of "aircraft-quality" die castings. In a typical unit, the X-ray tube is rated at about 140 kva and is mounted in a fixed position directly above a large fluorescent screen. Since this screen is protected by a sheet of bakelite and can be sealed away from direct

light, a more sensitive screen can be used than that which is used in the direct visual unit, for it will not lose sensitivity due to deterioration from light rays. Also it is not necessary to use several sheets of lead glass above the fluorescent screen since the operator does not view it directly, and additional sensitivity is gained as a result of this.

A fixed-focus camera is used to record the image on the screen, reducing it to one-sixteenth full size or less. The average camera is

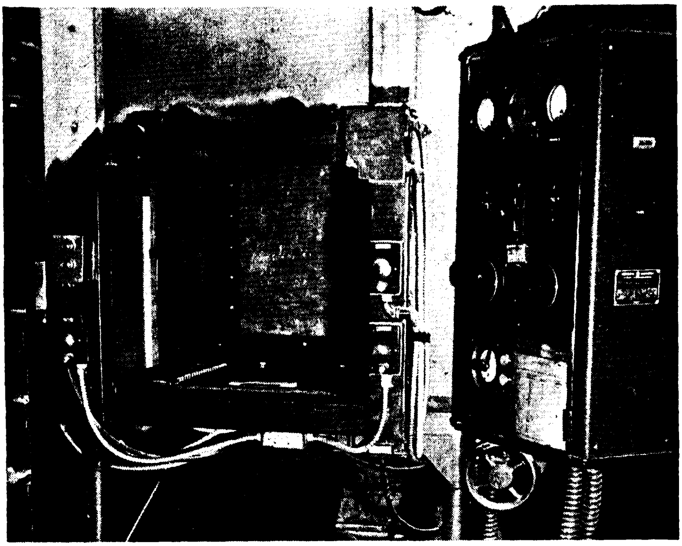


FIG. 11.7. A photo-roentgen unit—usually called a PR unit—is cheaper to operate than an X-ray machine, has better sensitivity than a fluoroscope. It is recommended for internal inspection of small to medium-sized parts.

equipped with an $f2.0$ lens and an electrically operated shutter. Exposures are made with the use of an electric timer.

In operation, a number of castings are placed on a piece of Presdwood which, in turn, is placed on top of the fluorescent screen. The doors are closed and an exposure made during which the image of the casting is photographed by the camera. The usual exposure is 10 sec. The Presdwood plate is removed from the machine and left with the castings on it until the film can be developed and examined. In this manner, the operation of numbering the castings can be eliminated, for it is only necessary to compare the film with the actual layout to determine which casting is which.

The advantages of the PR machine over the direct X ray is that the film cost is reduced considerably. Exposure time is less, and conse-

quently tube life is increased. The film also is considerably easier to examine, and it is not necessary to mark the individual castings with an identification number, since they need not leave the mounting board.

In comparison with the visual fluoroscope, it is possible to use a more sensitive fluoroscopic screen with a PR unit since it is sealed off from direct light. In addition, the photographic method of examining the fluoroscopic image is more accurate than the visual method. It has a

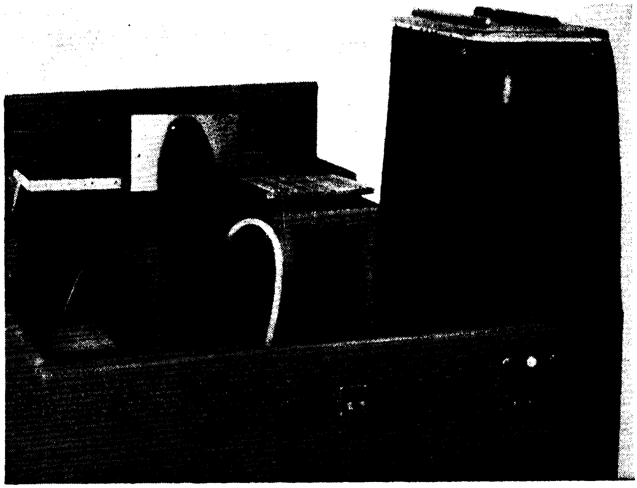


FIG. 11.8. Zyglo inspection bench for small parts, consisting of tanks for water and a fluorescent penetrant and of ultraviolet lamps. Zyglo examinations reveal small cracks and surface imperfections not otherwise visible to the naked eye.

disadvantage in that the exposed plate must be developed before the casting can be examined; but, on the other hand, a permanent record is made of all operations, and there can be no question of future procedures or standards in such a case.

To increase the capacity of a PR unit, it is only necessary to increase the number of personnel working on the machine. With nine men operating as a group, approximately 2,400 castings can be examined per hour. There is very little chance for increasing the capacity of a fluoroscope in a like manner since a visual examination requires much longer. The fluoroscope is also limited in capacity to a thickness of approximately ½ in. of aluminum, whereas with the PR machine up to 1½ in. of aluminum can be penetrated.

In comparison with a direct X-ray unit, the only disadvantages of the PR system are that the sensitivity is only 4 to 7 per cent, whereas with direct X ray it is 1 to 2 per cent. The contrast of the film also is not

so good, because the photograph is taken of the image on the fluoroscent screen, which in itself is of low contrast.

*Zyglo examination,** involving the use of fluorescent penetrant, is a nondestructive method for determining surface flaws such as cracks or checks. The part to be inspected is first coated with a penetrating, fluorescent fluid that can be removed by a water wash. After the penetrant is applied—either by dipping, spraying, or brushing—the part is set aside for from 5 min to 1 hr to allow the penetrant to work into any small surface defect, crack, or flaw, and also to allow the excess penetrant to drain back into the original container.

After this period, the excess penetrant is washed off the surface with water. After the part is dried, an absorbent powder is applied to the surface and the excess is shaken off; this powder acts to draw the penetrant out of the flaws and also reduces the fluorescence of any surface background. When the castings then are exposed to ultraviolet radiation, either from a high- or low-intensity mercury source or from a specially coated incandescent lamp, surface defects are revealed as bright and glowing fluorescent markings against a very dark background. A typical Zyglo inspection unit for small parts is shown in Fig. 11.8.

FINAL INSPECTION

The second or final inspection of all castings takes place after the trimming and machining operations are performed. Primarily, this inspection is intended to make sure that the operations are properly done and that flashes and burrs are removed. Machined dimensions are checked by means of gages. At the same time, the final inspector watches for casting defects that may have been missed in first inspection or for defects, such as porosity, that show up after parting-line flashes have been removed.

The gages used in final inspection are the usual "go" and "no-go" plug gages, ring gages, thread limit gages, and dial micrometers (Fig. 11.9). Flush pin gages or special gages for checking hole locations are also frequently used, as are indicator setups. Micrometers and height gages are sparingly used because they are generally slower to manipulate, and there is more danger that they may be improperly read. Snap gages are generally preferred to micrometers.

Whenever flatness or straightness of a part is of importance, it is the duty of the final inspection department to check this with surface plates, straight edges, or form gages made for the purpose. Any neces-

* Patented process of the Zyglo-Magnaflux Corporation, Chicago, Ill.

sary straightening is done by the final inspector by means of mallets or small arbor presses.

Attached to the final inspection department are a number of process inspectors whose duty it is to circulate through a specified portion of the machining department and to check the various machining operations

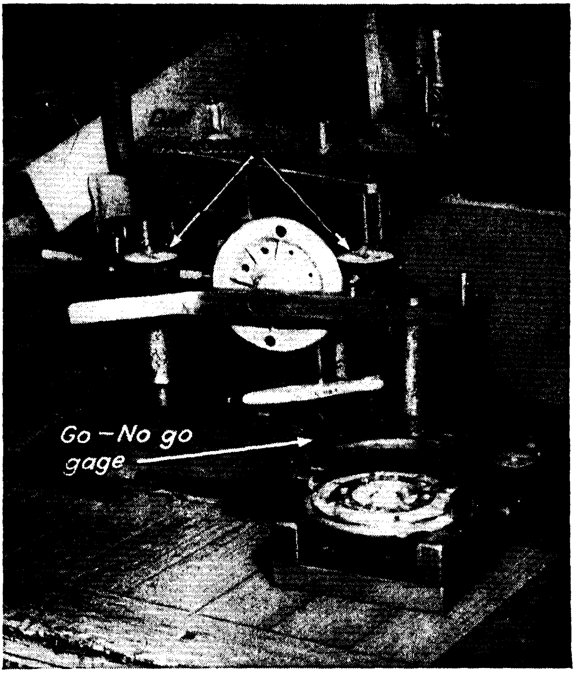


FIG. 11.9. Gaging setup to check accuracy on a machined die casting. The go-no-go gage is used to check the dimensional accuracy of the machined flange, while the dial indicators are used to determine eccentricity and flatness.

while they are being performed. When these inspectors find defective material due to poor workmanship or defective tools, they stop the job at once for correction. They also back-track through completed parts and either scrap or set them aside for repair so that they do not go on to subsequent operations. Process inspectors who do a good, thorough job can make final inspection much easier and even make it possible to put a lot of material through with only a sample-lot inspection.

Sample Inspection. Lot-by-lot sampling inspection came into extensive use during the recent war and has since been used more and more extensively by all types of industry. Charts which were developed during the war for use by government inspectors are worked out to deter-

mine the average quality level of any quantity of parts. The use of this method results in considerable savings in inspection costs.

Also, many users of die castings have installed quality-control methods of inspection in their plants and are now using sample-lot inspection on all incoming material. They are becoming increasingly reluctant to inspect 100 per cent any purchased material because of the cost involved and because they feel that it is the vendor's responsibility to supply them with parts that meet specifications. To meet this situation, it is necessary for the die caster to know what the customer considers an acceptable quality level and to be familiar with their sampling plan. With this knowledge it is possible to apply the same plan in the final inspection department at the die-casting plant. If the first inspection department has done its job well and the castings are properly cleaned, it should be possible to ship out castings that meet quality requirements without going through the costly process of 100 per cent final inspection.

TABLE 11.1. NORMAL LOT-BY-LOT INSPECTION TABLE FOR ACCEPTABLE QUALITY LEVEL OF 2.1 TO 3.0 PER CENT

Lot size	Sample size		Allowable defectives	
	First sample	Second sample	First sample	First and second samples
500 to 799	50	100	3	5
800 to 1,299	75	150	4	8
1,300 to 3,199	100	200	5	11
3,200 to 7,999	150	300	7	18
8,000 to 21,999	200	400	9	24
22,000 to 109,999	300	600	12	35

Many different sampling tables can be used in this type of inspection. While they are not all exactly alike, those which pertain to any certain quality level are very similar. A sampling chart used by Army Ordnance Inspection during the recent war is shown in Table 11.1. This is called a *normal lot-by-lot acceptance inspection table,* and the figures shown pertain to an acceptable quality level of 2.1 to 3.0 per cent; the maximum amount of defective material passed by this method is 3.7 per cent.

For example, suppose that a lot of 10,000 castings is to be inspected. Reference to the chart indicates that the first sample should be 200

pieces. One of the most important things to be kept in mind about this type of inspection is that samples must be selected at random and never picked from one portion of the lot. Therefore, if the lot is checked and

TABLE 11.2. NORMAL LOT-BY-LOT INSPECTION TABLE FOR ACCEPTABLE QUALITY LEVEL OF 0.26 TO 0.50 PER CENT

Lot size	Sample size		Allowable defectives	
	First sample	Second sample	First sample	First and second samples
500 to 799	50	100	0	2
800 to 1,299	75	150	1	2
1,300 to 3,199	100	200	1	3
3,200 to 7,999	150	300	2	4
8,000 to 21,999	200	400	2	7
22,000 to 109,999	300	600	3	8

found to consist of 20 cartons of 500 castings each, 20 pieces are selected out of each of 10 cartons. Next, the 200 samples are inspected. If 9 or fewer defectives are found, the entire 10,000 pieces are passed after disposing, of course, of the defectives.

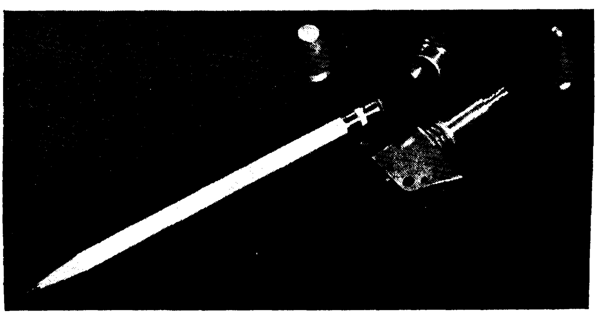


FIG. 11.10. Statistical sampling methods often are used during inspection of small parts, such as these zinc die castings, that are produced in large numbers. The sampling method chosen depends upon the acceptable quality level required and on other factors.

Suppose, however, that inspection of the first samples exposes 12 defectives. In that case, an additional 400 pieces are selected at random and inspected, as indicated by the chart. If the total number of rejects after this inspection is 24 or less, including the rejects from the first

sample, the lot is passed. If, in inspecting the first samples of 200 pieces, more than 24 defective parts are found, the entire lot is rejected for 100 per cent inspection at once.

Another sample chart of the same type but designed for a quality level of 0.26 to 0.50 is shown in Table 11.2. This table is calculated to ensure a maximum of 1.0 per cent defectives in the lot.

The savings that can be made by using statistical sampling methods are quite obvious, particularly when large quantities of castings are involved (Fig. 11.10). This is brought home very forcibly when one considers that it is necessary to inspect only 300 pieces of good-quality material to pass from 22,000 to 110,000 pieces.

OTHER FUNCTIONS OF THE INSPECTION DEPARTMENT

Besides dimensional, soundness, and surface-finish checks on die-cast parts, the inspection department usually has other responsibility such as (1) determining the pressure tightness of parts that will be subjected to heavy fluid pressures in service; (2) inspecting inserts and other incoming parts; and (3) inspecting castings that have been rejected by the customer.

Inspecting for Pressure Tightness. Some die castings are used in applications where it is necessary that they be pressure-tight. This is not particularly difficult in the case of small castings, especially those made of zinc alloy; even small aluminum castings made of S9 aluminum alloy will stand heavy pressures. With large parts it is difficult—in fact, almost impossible—to make a reasonable percentage of them leakproof. This is especially true of aluminum and magnesium alloys. It is necessary, therefore, to impregnate them very carefully in order for them to withstand pressure or to hold liquids. When properly impregnated, large castings are very satisfactory for applications such as gas tanks for outboard motors and the like.

Testing is done by final inspection in fixtures which seal the open parts of the casting with rubber pads (Fig. 11.11). The fixtures and castings are then submerged in water, and air at the specified pressure is introduced to the inside of the casting by means of a pipe through one of the rubber pads. The inspector watches for bubbles which will show up if the casting leaks.

Inspecting Inserts and Incoming Parts. Inserts are frequently cast in place in die castings. These may be steel or brass bearing bushings, steel or cast-iron cylinder sleeves for motor parts, field coils for electric motors, oilless bearings, studs, or many other shapes. These inserts are usually supplied by the customer who orders the castings, but in any case

are almost always obtained from an outside source. Hence, it is necessary to inspect the inserts when they are received at the die-casting plant to make sure that they are properly made and will fit in the die.

As a general rule, inserts are subjected to a sample-lot inspection when received and are either accepted on this basis or returned to the

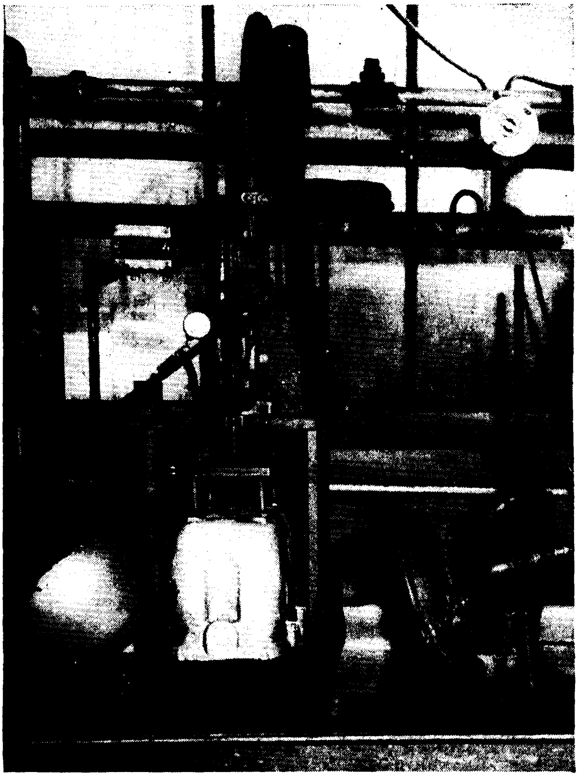


FIG. 11.11. Pressure-testing fixture for a gas-meter housing. The openings are sealed with rubber pads, air is forced into the inside of the casting, and the entire fixture is then immersed in water.

source. Only when the parts are needed at once for production are they inspected 100 per cent, in which case the defective material is returned.

Inspecting Rejected Castings. The inspection department also has one other function, namely, to check the quality of returned goods. All castings that have been rejected and returned by a customer are inspected carefully to determine (1) the type of defect; (2) whether the parts are actually outside acceptable standards; and (3) what must be done to prevent a recurrence of the rejection. Some returned material is beyond

repair and must be scrapped, but frequently the inspector finds that a large percentage may be salvaged and reshipped. In this case the inspector places "returned goods salvage" lot tickets on the material and moves it to the proper department for salvage.

Almost every die-casting plant has its own method of reviewing returned material after it has been inspected and classified by the inspector in charge. One way is to have the inspector select a few typical samples from each lot and to accumulate them over a period of a week. At the end of the week he also prepares a report of all returned material received during the week, reason for rejection, disposition, and value. This report and the sample castings are then reviewed at a meeting conducted by the chief inspector and attended by representatives of the casting, cleaning, and first and final inspection departments.

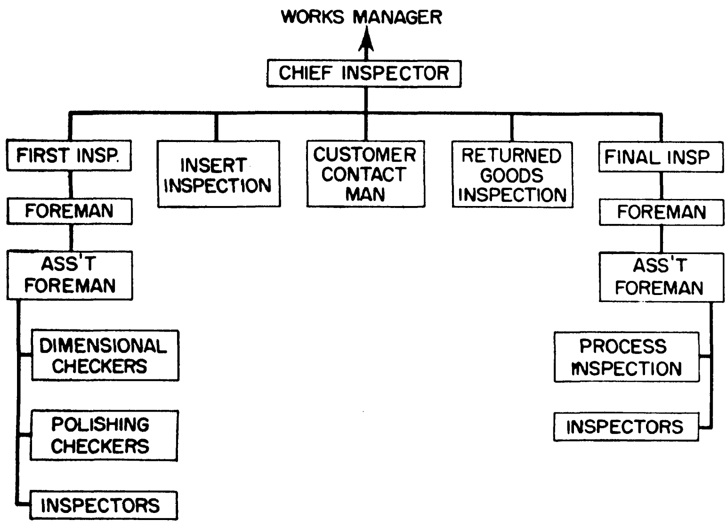


FIG. 11.12. Organization chart for an inspection department in a large die-casting plant. In small plants, one man may fill several jobs.

ORGANIZATION OF THE INSPECTION DEPARTMENT

The inspection department fills a very important place in the organization of any die-casting company. Much of the success and good reputation of the company depends upon its ability to maintain quality, to keep customers satisfied, and at the same time to keep costs down by adopting sensible and practical standards. It must be well knit, properly balanced, cooperative with all production departments, and dedicated to the idea of quality material at a competitive price.

The line of authority and responsibility in the inspection department begins with the chief inspector, who reports directly to the works manager. The sketch in Fig. 11.12 shows a typical organization chart of the inspection department of a large plant. Naturally, in smaller plants it might be necessary for some men to fill two or even several of the positions shown, but the general structure would be about the same.

CHAPTER 12

ESTIMATING THE COST OF DIE CASTINGS

In large die-casting job shops, a separate group in the engineering department usually is charged with the job of estimating the cost of parts that are to be made by die casting. In smaller shops or captive die-casting departments, the responsibility may be that of the engineer in charge, the productive superintendent, or the tool engineer. Regardless of the circumstances and of what individual or specific group is involved, the estimator must be able to visualize from a blueprint how the casting will appear in its finished form; how the casting is to be parted; where the ejector pins are to be located; the type of gating and venting to be used; and the extent of flash and fin removal that will be necessary. All these factors have a considerable bearing on the cost, particularly as they relate to machining and trimming.

The first duty of the estimator is to present an honest, accurate cost estimate of both die and casting. To do this a good deal of preliminary planning, engineering study, and consultation with the several authorities on metal and alloys, dies, casting, machining, finishing, and inspection must be held. The metallurgist is consulted for advice as to the best alloy to be used. The die and engineering departments recommend the type of die design best suited, its layout, the estimated number of hours required for its completion, and any other pertinent matter concerning the construction and cost of the die. The heads of the machining and trimming departments may be consulted regarding trimming and other tools required and their costs, as well as the cost of the operations to be applied to the casting. The chief inspector is conferred with when necessary regarding inspection tools and gages, as well as inspection costs.

Models. In the majority of cases the cost of die castings is estimated from blueprints of the parts, but whenever possible, the customer should be urged to furnish a model. A good working model, especially of any complicated or irregularly shaped part, greatly aids the designer and diemaker in determining lines or shapes that cannot readily be visualized or interpreted from a blueprint. It shows much better the customer's requirements. It helps in simplifying die construction and aids in reducing die costs. It obviates the need for preparing complicated templates,

saves possible errors in die construction, and aids in expediting die delivery. Models of parts to be die-cast can be and are used as patterns for plaster-of-paris forms, which are used on duplicating machines when cutting the impression in a steel die block.

ESTIMATING THE DIE COST

The first step in the estimating procedure is to analyze the part from a casting standpoint to determine whether the particular design of the part meets the requirements for die casting. If any modifications that would materially affect the application of the part are considered necessary, they are noted in remarks covering exceptions; such modifications might include redesign to eliminate unnecessary undercuts, to avoid thin sections of die steel, to omit holes that are impractical to cast, to reduce the thickness at walls and heavy sections, and to increase the size of small holes.

In those cases where radical changes are suggested, a sketch covering the proposed changes is made and submitted to the customer with the proposal. This analysis also shows the best method of arranging the part in the die and indicates where the parting-line seams will appear on the casting. Such decisions may be influenced by the type of gating used, the method of ejection of the casting from the die, the number of holes and openings on the faces of the casting, the importance of surface finish of the various parts of a casting, and the economical removal of parting-line seams and flashes.

The next step is to decide upon the type of die to be used: a single- or multiple-impression die; a combination die; an interchangeable die, that is, one in which similar parts with minor variations can be cast from the same impression by the use of interchangeable die parts; or a unit die. The type of die and the number of impressions used are governed by the size and bulk of the part, the number of side core pulls necessary, the ease of gating, and the quantity of castings required per day or week.

After the style and type of die have been determined and indicated on an estimate form such as is shown in Fig. 12.1, the estimator proceeds to compute the cost of the die by estimating the number of hours required for the diemaking department to make it and for an engraver to engrave it, should any art engraving or straight-line engraving be necessary. These estimated times are recorded in the proper space on the estimate form and are later converted to dollar cost.

The engineering and drafting hours necessary to design the die are then determined and recorded. By a rough layout of the die or a scale development of the over-all size and thickness of the die blocks, the

PART NAME ____________________

PART NO. ____________________ METAL COST ____________________

DELIVERY SPECIFICATIONS ____________________ CU __________

ZN __________

ALLOY ____________________ AL __________

ETC. __________ __________

ESTIMATED WEIGHT OF CASTING ____________________ TOTAL METAL __________

TYPE OF MACHINE ____________________ MELTING COST (INCLUDING METAL LOSS AND DROSS) __________

MACHINE RATE PER HR. (INCLUDING LABOR AND BURDEN) ____________________ TOTAL COST PER LB. __________

DIE SET COST ____________________ METAL COST PER M __________

DETAILS / QUANTITIES →				
	PIECES/HR.	COST PER M	PIECES/HR.	COST PER M
DIE SET COST PER M				
CASTING COST PER M				
REMOVING GATES (INCLUDING BURDEN)				
FIRST INSPECTION (INCLUDING BURDEN)				
TRIMMING AND MACHINING (TOTAL)				
FINAL INSPECTION (INCLUDING BURDEN) IF NOT INCLUDED AS PART OF TRIMMING DEPT. BURDEN				
TOTAL FABRICATING COST PER M				
METAL COST				
SPECIAL ITEMS (INSERTS IF NOT SUPPLIED AND PLATING, ETC.				
TOTAL MANUFACTURING COST PER M				
DIE AND TOOL REPLACEMENT				
SHIPPING AND PACKING				
FREIGHT				
GENERAL ADMINISTRATIVE AND SELLING				
TOTAL COST				
PROFIT				
SELLING PRICE				
ADJUSTMENTS				
PRICE QUOTED-PER M				

MEMO OF PROPOSAL:

*TRIMMING AND MACHINING OPERATIONS

LABOR COST				
____________________				
____________________				
____________________				
____________________				
BURDEN-BENCH OPERATIONS				
-MACHINE OPERATIONS				
TOTAL TRIMMING AND MACHINING COST				

FIG. 12.1. Form for estimating the cost of die castings. All factors—from die cost to administrative and selling cost—are included.

TOOL AND DIE COST

FOR ______
ADDRESS ______ DATE ______
ATTENTION OF ______ QUOTATION NO. ______
TYPE OF DIE { SINGLE CAVITY / MULTIPLE CAVITY / COMBINATION, ETC. ______ DIE NO. ______
IMPRESSIONS IN DIE ______ DIE DELIVERY DATE ______
OUR DRAWING NO. ______ THEIR DRAWING NO. ______

DETAILS	DIE COST INCLUDING EJECTOR BOXES CORE MOVEMENTS AND BASES				TRIMMING TOOLS & FIXTURES INCLUDING TRIMMING DIES REAMING, TAPPING & DRILLING FIXTURES, INSPECTION TOOLS			
MATERIALS								
STEEL - KIND								
- SIZE								
- WEIGHT								
- COST PER LB.								
STEEL COST								
CAST IRON								
PLATES, ETC. ______								
TOTAL MATERIAL COST								
LABOR								
DIEMAKERS __HRS.@ ______								
TOOLMAKERS __HRS.@ ______								
HELPERS ______								
OVERTIME ______								
TOTAL LABOR								
BURDEN @ ______ PER HR.								
HEAT TREATING @ ______ PER LB.								
DRAFTING @ ______ PER HR.								
ENGRAVING @ ______ PER HR.								
OUTSIDE WORK ______								
SPECIAL CHARGES ______								
COST OF SAMPLES (INCLUDING DIE SET-UP, ADJUSTMENTS AND CORRECTIONS)								
COST TO CONSTRUCT DIE								
TOTAL COST OF TOOLS, JIGS AND FIXTURES								
TOTAL COST OF DIE AND TOOLS								
DIE AND TOOL CHARGE QUOTED								

REMARKS :

I, - AMERICAN DIE CASTING INSTITUTE

FOLD HERE

SALESMAN	ESTIMATED BY	FIGURED BY	CHECKED BY	APPROVED

FIG. 12.1. (*Continued.*)

estimated weight of the steel is calculated and recorded. At this point, consideration is given as to whether impressions will be in a solid die block or in impression blocks that can be inserted into a holding-die block made of lower grade steel. The type and size of the die base or unit die are also determined, together with the amount of steel and other material used in cores, slides, locks, gears, and other die components.

The weight of various blocks and segments of the die that must be heat-treated or nitrided is then calculated so that the cost of heat-treating can be subsequently computed.

Considering the type and size of die; the nature of the casting, whether simple or intricate; the type of finish required on the part; and other requirements such as density or pressure tightness, the cost of making samples is judged.

With all the foregoing factors established, the next step is to convert them by means of charts and tables into dollars and to apply respective burden or overhead costs to the various labor-cost increments. Material costs are similarly converted from pounds to dollars. With the cost of heat-treating, nitriding, and making samples similarly established, the estimate is then totaled to determine the final cost of the die-casting die.

A similar procedure is followed in estimating the cost of the trimming and machining tools and all necessary inspection gages and checking and testing fixtures. Knowing where the parting line will occur, where the casting will be gated, and where fins and flashes will appear, the estimator decides upon the type of trimming die and other cleaning and machining tools and proceeds to estimate the time required to construct them. These factors, as in the case of the die-casting die, are converted to dollars.

ESTIMATING THE CASTING COST

As an initial step in estimating the cost of a casting, the weight of the part must be calculated from a blueprint, if a model or sample is not available. Weight calculation is accomplished by dividing the part into a number of simple geometrical sections whose volume can be calculated. Figure 12.2 shows a detailed description of the weight-calculating procedure. The three views at the top represent the part as received for quotation. The encircled numbers indicate the various geometric solids that the part is divided into, while the lettered items are the deductions to be made. The views on the left show in detail the cross section of each lettered or numbered geometric solid. The additions and deductions in the center of print show the exact dimensions and volumes as

computed, with a full description of each item shown at the bottom. When the total of these geometric solids has been determined and the proper deductions made for cored holes and openings, the resulting volume of the part is converted to weight by multiplying the volume by the specific weight of the metal or alloy to be used.

Depending upon the size of the casting machine and upon whether one or more men are required to operate it, the hourly rate of production is determined on the basis of the machine operating at peak efficiency. Factors that affect the speed of operation—the number of impressions in the die, the number of cores and the method of actuating them, the number of loose pieces or inserts in the die, the size and weight of the casting, surface-finish requirements on the casting, the frequency of quality-control inspection, and the type of alloy to be cast—are given due consideration in establishing the hourly rate of production.

At the same time, a die-set symbol is established, based on time-study records of the time involved in setting up die-casting dies; these records in turn are governed by the size of the casting machine, the size of the die, the number of core pulls and slides, and the method of ejection. These designations are later converted by chart reference to cost in dollars. It is then necessary to estimate the life of the die in order to compute the cost of the replacement. Here the estimator must consider the type of metal, the weight of metal input, surface-finish requirements, tolerance and accuracy standards called for, and other factors having a bearing on die life. He relies heavily on his past experience with castings of similar shape and size. The estimate is recorded in terms of hundreds of thousands of shots and subsequently converted into a cost rate per thousand.

The time and speed of removal of gates and first inspection operations are also estimated. This includes the time of X-raying or fluoroscoping a percentage of or all the castings, which obviously depends upon the degree of density specified or required in a given casting. The time-study procedure used in actual shop practice is followed in estimating the time at each step of the inspection; for example, the time required to pick up the casting, to inspect it, to deposit it in a shop box or truck after inspection, and to break the gate or remove it by other means.

The inspection cycle itself covers visual examination for surface imperfections, gate porosity, position of ejector pins, core or slide blow, and oil stains, in addition to dimensional checks. All these cost factors are recorded in the removal of gates and first inspection space on the estimate card and are later converted to cost value.

The point has now been reached where the cost of trimming and machining the casting must be established. Such operations may be

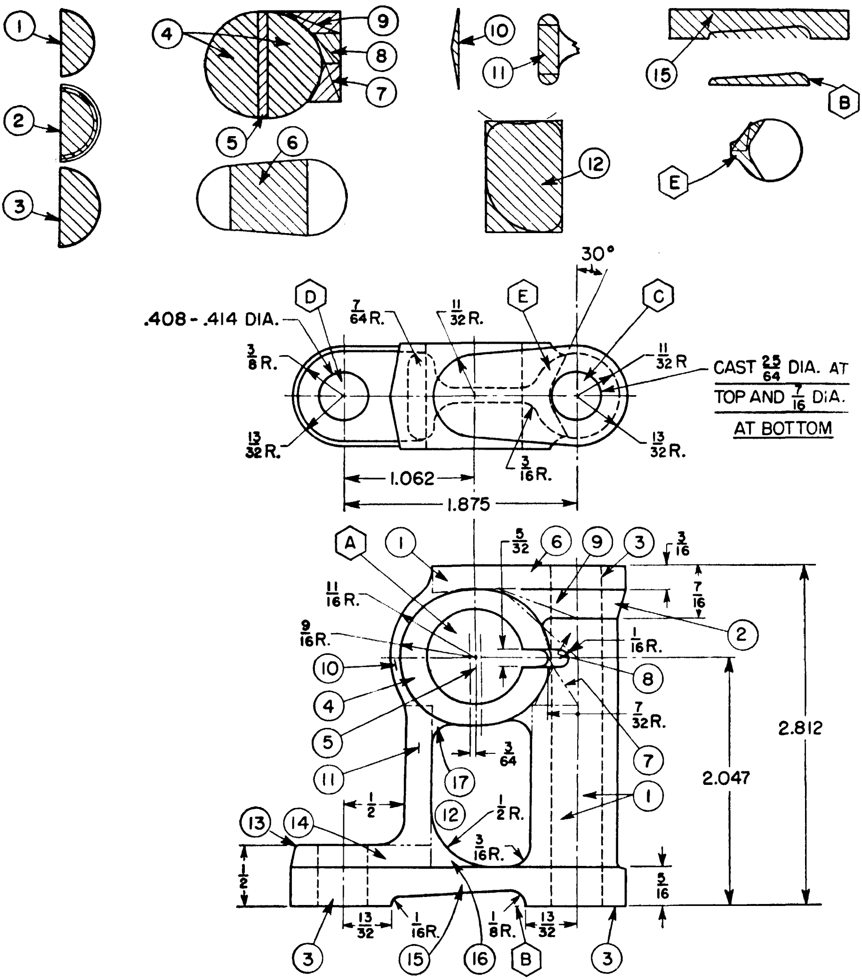


Fig. 12.2. Estimating the weight of an irregular casting to determine material cost is done by dividing the part into a number of simple geometrical sections whose weight can be calculated.

ADDITIONS

1. Area of circle × total length (3 places) × ½, to give a half circle = volume	.371 × 3.640 × ½	=	.675
2. Average area of circle × length × ½ for half circle = volume	.442 × .250 × ½	=	.055
3. Area of circle × total length (3 places) × ½ for half circle = volume	.518 × .812 × ½	=	.210
4. Area of circle × length = volume	.994 × .875	=	.870
5. Length × width × thickness = volume	.094 × 1.125 × .875	=	.093
6. Length × average width × thickness = volume	.812 × .750 × .188	=	.114
7, 8, and 9. Rectangles divided into two triangles,	.422 × .219 × .687	=	.063
length of the base × ½ the length of both alti-	.437 × .172 × .687	=	.051
tudes = area × thickness = volume	.687 × .164 × .750	=	.085
10. Length of the base × ½ the average altitude × length at center of gravity = volume	.875 × .039 × 1.141	=	.039
11. Area of circle × length and area of rectangle ×	.038 × 1.125	=	.043
length = volume	.219 × .531 × 1.125	=	.131
12. Area of rectangle × thickness = volume	.812 × 1.203 × .125	=	.122
13. Average area of circle × length × ½ = volume	.479 × .188 × ½	=	.045
14. Average width × height × length = volume	.188 × .781 × .719	=	.106
15. Length × width × thickness = volume	1.875 × .312 × .812	=	.475
16. Area of ½-in. fillet × total thickness minus wall thickness = volume	.0537 × .625	=	.034
17. Area of $\frac{3}{16}$-in. fillet × total thickness minus wall thickness = volume	.0076 × .625	=	.005
18. Area of $\frac{3}{16}$-in. fillet × total length through center of gravity, both sides = volume	.0076 × 3.125 × 2	=	.048
			3.264

DEDUCTIONS

a, *c*, and *d*. Area of circle × length = volume	.479 × .875	=	.419
	.135 × 2.812	=	.379
	.134 × .500	=	.067
b. Average length × average width × thickness = volume	1.031 × .094 × .812	=	.079
e. Area is found same way as (6)(7)(8) × average thickness × 2 = volume	.312 × .125 × .141 × 2	=	.011
			.955

The volumes of the additions are totaled and the total of the deductions is subtracted from this; this sum is then multiplied by .096, which is the constant of S-1 aluminum, giving the estimated weight.

$$\begin{array}{r} 3.264 \\ -.955 \\ \hline 2.309 \\ \times .096 \\ \hline \end{array}$$

.222 lb of S-1 aluminum

FIG. 12.2. (*Continued.*)

divided into two classes, namely, *bench* and *machine,* with the view of applying fair and proportionate burdens to each class of operation. The time involved for each bench operation, such as filing, burring, and bench fixture trimming, is listed separately. The time required for each machine operation employing machine tools of various types and consisting of power-press trimming, drilling, reaming, tapping, facing, and the like is also recorded separately. At this point consideration is also given to salvage operations necessary in completing a casting. The time estimated for all these operations is also based on the time-study procedure used in actual shop practice and includes allowance for rest and delay and for losses due to rejects. The respective labor increments when completed are totaled and converted to a rate per thousand castings, to which respective burdens are subsequently applied.

As in the case of first inspection, the time required for the final inspection operations is detailed, starting with picking up of the casting and ending with the disposal of it after visual inspection and gaging of machine operations has been completed. Where castings require straightening or pressure-test checking, these operations are accomplished at final inspection and made a part of such cost.

TOTALING THE PART COST

When all the time and cost factors have been recorded on the estimate card, the final step is to convert them to dollars.

From the die-set symbol applied by the estimator, the calculator, by referring to a chart, applies the dollar cost for die setting, depending upon the length of run in the form of a rate per thousand parts.

From the maximum-production figure established, the calculator determines from experience data the hourly rate of production that may be expected for the quantity to be produced and then determines the rate per thousand for casting-labor and burden costs for either one- or two-man operation, based on the speed of production. If X ray or fluoroscoping is indicated on the front of the card, that cost is also converted and shown in the column. The two categories of bench and machining labor are shown next in the column with their respective burdens applied, and are followed by the final inspection cost, including straightening and pressure testing when required. The total of the column up to this point shows the total fabrication cost per thousand parts. The next factor of cost to be added is that of metal, which is derived from the product of the weight shown at the top of the card and the alloy cost. On the basis of the metal value involved, the dross loss is established; and on the basis of the weight of the casting, the melting cost is deter-

mined and added to the cost of metal. The accumulated total up to this point represents the so-called manufacturing cost.

Based on the weight of the casting, the shipping expense is developed. Packing material is based on the number of castings to a container, computed at current-day costs of cartons, nests, and other materials. Here past experience on similar castings is referred to in determining the size and type of packing to be used. When castings are quoted on a delivered basis, the cost of transportation is computed, including a predetermined percentage for tare plus the weight of inserts, if such are cast or assembled in place.

The die life having been previously determined and indicated on the cost-estimating card, it is now converted to a cost rate per thousand parts, based on the cost of the die and its estimated life. Tool-replacement cost is similarly determined and included in the cost column. Where the die is so constructed as to effect interchange for producing various parts of similar shape, such interchange cost is spread over the quantity involved. When inserts are cast in place, the cost of handling, inspecting, and salvaging them is provided for as part of the cost of production. The selling and administrative costs, based on labor and burden, are added into the column.

To the total estimated cost is added a percentage of profit in arriving at the final selling price per casting.

Naturally, the procedures outlined above and the methods of calculating the various costs often vary from plant to plant and from company to company. For example, they may differ somewhat between a die-casting jobbing plant and a small, captive die-casting department in a large manufacturing plant. But the same principles apply, whether the methods and procedures are similar or not.

CHAPTER 13

SAFETY IN THE DIE-CASTING PLANT

Safety is an extremely important aspect of die casting—perhaps more so than of other metal-fabricating processes because of the number and type of operations involved. Safety standards and rules must be established and rigorously followed in each department—from the receiving department through the foundry, casting, machining, and finishing departments to part storage—if accidents are to be kept at a minimum and health hazards are to be eliminated.

MELTING AND ALLOYING DEPARTMENTS

The operation of a foundry, which consists of melting and distributing molten metals, piling and storing raw materials, and remelting gates and superfluous metal, requires good supervision and planning if accidents are to be avoided.

1. All floors should be level and in good repair. Floors also should be free of scrap and other debris. Good housekeeping not only prevents accidents but also contributes to a more even flow of materials and finished products.
2. Safety clothing is necessary to protect workers from burns. A safety shoe of the gaiter type should be worn so that if metal is splashed on the foot, the shoe can be removed without being unlaced. These shoes are made with a safety toe cap. Leggings are necessary to prevent splashed metal from running down the leg into the shoe. Goggles should be worn by all melting and alloying personnel to avoid eye injuries from splashed metal. Gloves must be worn by all workers in this department if serious burns are to be prevented.
3. Cold ingots on which moisture has condensed should not be charged into molten metal in pots or furnaces. An explosion may result that will shower the surrounding area with hot metal.
4. All flues, furnaces, and other hot equipment with which the worker might come in contact should be properly guarded or insulated to prevent minor burns.
5. All bull ladles and power equipment must be handled carefully to

prevent molten metal from being spilled over workers. A warning signal or bell should be used on each metal transport.

6. Pockets where gas might accumulate should be tested periodically with an explosion meter. This applies particularly to areas in which gas-heated equipment is located, since slight leaks and the absence of drafts may contribute to the formation of an explosive mixture.

7. Proper ventilation and the removal of smoke and fumes are necessary as a health measure. Fatigue, eye strain, and headaches often are caused by improper ventilation. The removal of high concentrations of dust and fumes presents an engineering problem of great importance. Some of the methods employed to control dust are the use of

a. Exhaust systems or suction devices that entrap dust at its point of origin.
b. Water to lay dust or fumes and keep them out of the atmosphere.
c. Enclosed, properly ventilated areas for operations, properly exhausted.
d. Increased ventilation, thus diluting the amount of dust in the air and decreasing its concentration.
e. Helmets, or approved respirators where intermittent exposures not otherwise controllable are involved.

Where there is a possibility of a concentration of dust, smoke, or fumes it should become the policy to make periodic surveys. This survey can best be made by an electrostatic dust and fume sampler. Such instruments provide highest precision in the quantitative sampling of dusts, fumes, and mists. They are especially adapted for sampling metal fumes that occur whenever metals such as lead, zinc, cadmium, manganese, and chromium are heated.

8. In a magnesium foundry, the workers should wear fireproofed clothing, if possible. An adequate number of fire extinguishers should be available and the workers should be trained to use them. Fire blankets, kept in metal cans, should be located in easily accessible places.

CASTING DEPARTMENT

Die-casting machines may cause other kinds of accidents. In fact, before the need for proper safety controls was recognized, many maiming injuries, such as the loss of fingers, hands, arms, and at times even deaths were caused by the interpositioning of parts of the body between the closing halves of the die.

A great deal of thought has been directed toward eliminating these

dangers. It was found that if both hands were required to push and hold the controls for closing the machine, most of the accidents could be avoided. Therefore, modern machines usually incorporate some obstacle to the closing of the machine. This device can be removed only by holding one hand on the control button of a solenoid that will lift it from the path of travel while the other hand operates the button to close the machine. If the safety circuit is broken by releasing the contact before the machine has completely closed, the device will drop into its original position, or into succeeding ones, and prevent the machine from closing completely.

Another type of safety device that is used to prevent injury from closing dies is the photoelectric light barrier. In this type of safety device, a light source is directed through a series of mirrors back and forth several times across the opening of the machine. If this light barrier is interrupted by any part of the body or by any other solid object, the machine will reverse direction, travel to the fully opened position, and not close again until the starting button is operated.

Many accidents may occur during the mounting or dismounting of the dies. Since these dies are large blocks of steel that are usually handled with chain hoists, it is imperative that the chains and hooks be examined regularly for flaws, that the eyebolt in the die be selected carefully, and that the eyebolt be properly screwed into the die block. Safety shoes should be worn in all departments where heavy blocks of steel are moved.

During the die-setting operation, the main hydraulic valves on the machine should be closed, and the electric power to the machine shut off. If this is done every time work is performed on the die, many maiming accidents will be avoided that might otherwise occur by inadvertently pushing the closing buttons on the machine.

The ejector-lever handle will be forcibly swung around if the ejector pins are not retracted before the die is closed. To prevent this type of accident, which can cause fractured skulls and other head injuries, many machine designers include an electrical interlock in the machine-closing circuit, so that unless the ejector pins are safely drawn back, the machine cannot be closed. Some designs for ejectors utilize a round wheel rather than a lever to operate the rack.

During the actual process of making die castings, a spray of metal may be forced from between the die halves. This occurs when the machine has not been properly adjusted or when a piece of flash from the preceding shot remains on the die face. To prevent injury to the operator and to nearby personnel, shields are usually erected between machines; and everyone working in, or passing through, the casting room

should be forced to wear goggles to protect his eyes. No one should walk between machines while a shot is being made.

When a shot is made on a cold-chamber casting machine, metal may be sprayed out of the pouring hole of the shot sleeve. To avoid injury from this cause, the pouring ladle should be inverted over the hole as the shot is being made. Care also must be exercised in making the first shot after a die is mounted, or after it has been repaired on the machine, to cover the die with an asbestos blanket, so that in case anything is wrong and the cast metal is sprayed out, no injuries result.

Since the plunger tips of cold-chamber machines are water-cooled, the shot sleeve and the plunger tip must be examined for leaks before a machine is started, even after an overnight shutdown, to prevent the explosion that would occur if hot metal were poured into a sleeve containing moisture. The sleeve should be heated before the first shot to drive out any condensed moisture.

For the same reason, extreme care must be taken to preheat all ladles used before dipping them into the bath of molten alloy.

MACHINING AND TRIMMING DEPARTMENTS

The machining department is another department where serious accidents may occur, since punch presses, drills, lathes, and other moving machinery are used.

Drilling is often performed by women. Their long hair may be caught in the rotating drill, and therefore it is mandatory that they wear caps or snoods to cover their hair completely. Foot accidents are possible since many castings are moved in tote boxes. No open-toed shoes should be allowed, and safety shoes with toe protection are recommended. Even though the castings may have sharp edges, protective gloves may not be worn near any rotating equipment, since they may be caught by the work, and the employee drawn into the machine. Finger rings may cause the same kind of accident, and should not be worn. No loose clothing, such as four-in-hand ties or long, loose sleeves, should be worn when this kind of work is being done. Wherever chips are formed, or if danger from blown chips from nearby stations exists, face shields or goggles must be worn.

Punch and foot presses can be made safe. The use of two switches, both of which are required to start the press, ensures that the operator's hands are out of danger as the press starts. Sweep rods, operating from the descending ram, will push the operator's hands away if he attempts to bring them into danger. Constant vigilance is required to prevent these safety devices from being circumvented; for example, one switch of

the two-switch circuit may be locked in place, thus freeing one hand of the operator. In some cases, a screen can be placed around the press, and the work pushed into place on a fixture.

Proper lifting methods must be enforced in this department. If a worker attempts to lift from the wrong position, or to lift too heavy a load, hernias or back strains may result.

The use of cutting oils and emulsions on lathe and drill-press operations can become a definite health hazard if proper precautions are not taken. All cutting oils and compounds should be changed periodically, because they become contaminated through human contact and by foreign matter being thrown into the pan or reservoir. When this contaminated liquid penetrates the pores of the skin, it usually causes dermatitis. All cutting oils are sterile when purchased; therefore, they are harmless to the skin. Employees who are required to use cutting oils should be advised to change clothing regularly to prevent the clothing from becoming saturated and starting skin irritations. Personal hygiene is the most effective preventative of dermatitis.

MAINTENANCE DEPARTMENT

Maintenance personnel are required to work all over the plant. All safety appliances and regulations applying to specific departments must also cover these men. In addition, they must exercise certain other precautions.

Ladders must be examined regularly to ensure that all rungs and side bars are in good condition; they should not be painted, because paint might conceal defects. They must always be placed on a level spot, or if this is impossible, one man must be assigned to hold the ladder. When a man must work overhead, he should fasten all his tools to his safety belt. He should not be allowed to overreach his position. When he is working on casting machines, presses, or other moving machinery, the fuse should be pulled from the line so that the equipment cannot start. When heavy equipment must be moved, enough men to do the work safely should be assigned to prevent strains, hernias, or other accidents.

Welders. It is mandatory that all welders wear proper head and eye protection on welding or burning operations. Portable shields should also be provided for the protection of workers near the welding operations. In the case of an overhead welding job, fireproofed canvas drops must be provided to catch the falling sparks and pieces of hot metal, which are definite fire hazards.

The following are a few safety recommendations for all welders:

1. Never under any circumstances use a steel drum or barrel as a table to do a temporary welding or burning job.
2. Keep all combustible materials such as paper, rags, or inflammable liquids away from welding booths.
3. Place oxygen and compressed gas cylinders far enough away from the welding position so that they are not overheated by radiation from the weld, by sparks, or by misdirection of the torch flame.
4. Provide sufficient space around and between the cylinders so that the regulators can be reached quickly in an emergency.
5. Do not allow compressed-gas cylinders to come in contact with electric welding apparatus or electrical circuits.
6. Never use an acetylene torch at pressures above 15 psi.
7. Release the pressure in the regulator when stopping work for periods of an hour or longer.
8. Keep oxygen cylinders and fittings away from oil or grease. Do not handle oxygen cylinders or apparatus with oily hands or gloves, since such materials may ignite violently in the presence of oxygen under pressure.
9. Always open the cylinder valves slowly. Never use a hammer on the valve wheel in attempting to open or close the valve.
10. Inspect hoses and equipment periodically; any defects should be reported to the foreman at once. Use soapy water—never flame—to detect leaks in hoses or piping systems.
11. Fasten compressed-gas cylinders in an upright position to the workbench, a post, or portable equipment so that they cannot be knocked or pulled over.
12. Know where the nearest fire extinguisher is located, and know how to use it.

SAFETY EDUCATION AND ENFORCEMENT

It is, of course, impossible to cover any but the most important aspects of die-casting safety in a few pages. Besides the previously listed precautions, which apply specifically to die casting, the safety programs in effect in any industrial plant must also be enforced in the die-casting plant.

The formation of a safety organization, headed by a safety engineer or director, is important. Safety committees, made up of representatives of labor and management, should be established in each department of the plant.

The function of such safety committees is to make regular inspection trips through each department, to check all safety equipment, and to report on any that requires attention or repair. The mechanical and elec-

trical safety devices on die-casting machines, power presses, and other equipment should be inspected periodically to ensure their proper working order. Similarly, any defects in hooks, chains, or cables on hoisting devices must be reported and immediately repaired or replaced. Aisles and passageways must be kept clear of any obstructions. Metal must be safely stacked. Fire equipment and means for escape must be checked and kept clear of obstructions. Educational safety meetings should be held for the committee and for other personnel such as foremen and lead men in various groups.

A safe plant is a good plant to work in, and good safety administration is chiefly an educational project to show all workers in the plant that safety rules do not reduce earnings but in fact help to increase them.

GLOSSARY OF TERMS USED IN DIE CASTING

Acid refractories. Refractories that react chemically with a base such as lime. The most important acid refractory materials are the clays and various forms of free silica.

Acid steel. Steel melted in a furnace that has an acid bottom and lining, and under a slag that is dominantly siliceous.

Age hardening. An increase in hardness (and strength) due to the passage of time. This phenomenon can be accelerated by heating.

Aging. A phenomenon occurring with the passage of time, consisting of a change in metallurgical structure which is evidenced by changes in physical properties and dimensions.

Air-injection machine. That type of die-casting machine in which air pressure acts directly on the surface of molten metal in a closed pot (gooseneck) to force the metal into the die.

Alkali metals. The elements lithium, sodium, potassium, rubidium, and cesium, each of which is the parent of a powerful base or alkali.

Alkaline-earth metals. Metals of group *2a* of the periodic system, including calcium, strontium, barium, and radium.

Alloying. Adding to a metal one or more different elements to change its characteristics and properties.

Alpha iron. The form of iron that is stable below Ac_3 (910°C, 1670°F) and characterized by a body-centered cubic crystalline structure.

Alumel. A nickel-base alloy containing about 2.5 per cent manganese, 2.0 per cent aluminum, and 1.0 per cent silicon, used chiefly as a component of pyrometric thermocouples.

Alumilite process. A patented chemical finishing process for aluminum.

Amorphous. Lacking crystalline structure or definite molecular arrangement; without definite external form.

Amorphous metal. Metal in which the atoms are not arranged in a geometrical pattern.

Anodic oxidation. A method for producing an oxide deposit on aluminum or its alloys. The aluminum is made the anode, while the cathode can be made of lead, iron, or carbon. The electrolyte is sulfuric acid or chromic acid, or phosphoric, oxalic, or sulfamic solutions. Also called *anodizing* or *anodic treatment.*

Arbor. A bar or mandrel on which a core is built up.

Arrest points. Those parts of a curve showing constant temperature on heating or cooling.

Austenite. A solid solution in which gamma iron is the solvent; characterized by a face-centered cubic crystal structure.

Austenitizing. A trade name for a patented heat-treating process that consists of quenching a ferrous alloy from a temperature above the transformation range in a medium having a rate of heat abstraction sufficiently high to prevent the formation of high-temperature transformation products; and in maintaining the alloy, until transformation is complete, at a temperature below that of pearlite formation and above that of martensite formation.

Basic refractories. Refractories that react with silica and form silicates; the term is commonly restricted to lime and magnesia and their carbonates.

Basic steel. Steel melted in a furnace that has a basic refractory bottom and lining, and under a slag that is dominantly basic.

Bauxite. A claylike substance, colored white, yellow, brown, red, or black, streaked identical in degree. Whitish when silica is predominant or reddish when oxide of iron is largely present. White bauxites are chiefly used for the production of aluminum sulfate and the alums. Red bauxites form the raw material for the preparation of alumina and therefore of aluminum. Also, the source of artificial emery, corundum, cement for kiln linings, refractories, paint pigments and fillers, and others.

Billet (nonferrous). A section of an ingot, hot-worked by forging, rolling, or extrusion; or a casting suitable for rolling or extrusion.

Blister. A surface bubble or eruption caused by expansion of gas trapped within the casting or beneath the plating on the casting. Usually caused by heating.

Blooms (ferrous). Semifinished products hot-rolled from ingots. Rectangular in cross section with rounded corners.

Blowholes. Voids or pores that occur in some castings because of trapped gases.

Box. Part of the ejector half of the die that contains the ejector mechanism or core mechanism or both.

Brightener. Material added to an electroplating bath to give the deposited metal a highly reflective surface.

Bull ladle. A large container used to transport or pour molten metal.

Burned casting. A casting that is heated above the eutectic temperature during heat-treatment, thus causing melting of the eutectic. In most cases, such castings become brittle and may show blisters.

Carbide. A compound of carbon with one or more metallic elements.

Carburizing. The introduction of carbon into a solid ferrous alloy by heating the metal in contact with a carbonaceous material—solid, liquid, or gas—to a temperature above the transformation range and holding at that temperature for a specified period of time. A case-hardening process.

Case-hardening. Hardening a ferrous alloy so that the surface layer or case is made substantially harder than the interior.

Casting. The metal shape obtained by pouring metal into a mold.

Casting stability. State of possessing no stresses that effect the accuracy of machined dimensions.

Casting strains. Strains resulting from the cooling of a casting; these strains are accompanied by residual stresses.

Cast structure. The structure, on a macroscopic or microscopic scale, of a cast alloy that consists of cored dendrites and, in some alloys, a network of other constituents.

Catalyst. A substance that accelerates or promotes a chemical change, but is itself unaltered at the end of the process.

Cathodic protection. The use of a particular metal as cathode in the corrosion cell as a means of protecting that metal against electrochemical corrosion. This may be accomplished by the attachment of a more anodic metal or by the use of an applied potential.

Cavity. The die impression that gives the casting its external shape.

Cementite. A compound of iron and carbon known as iron carbide, which has the approximate chemical formula Fe_3C and is characterized by an orthorhombic-crystalline structure.

Centrifugal casting. A casting produced in a mold that is rotated during solidification of the casting.

Charging. Loading a batch of castings into a heat-treating furnace. Also loading a charge in a melting furnace.

Chemical deposition. The precipitation of one metal from a solution of its salt by the addition of another metal or reagent to the solution.

Chemical slab mold. A permanent mold that is used to obtain samples for either chemical or spectrographic analysis.

Chinese script. A configuration typical of the constituents in cast aluminum alloys containing specific amounts of iron and silicon. This term applies also to a similar structure found in magnesium alloys containing silicon.

Chrome brick. Brick made from refractory chrome ore.

Cleavage plane. A crystallographic plane on which fracture occurs in a crystal or grain of metal.

Coalescence. The growth of particles of a dispersed phase by solution and reprecipitation; the growth of grains by absorption of adjacent undistorted grains.

Cogging. Rolling or forging ingots to blooms or billets.

Coining. A process of impressing images or characters on a die or punch onto a metal surface.

Cold-chamber machine. Casting machine wherein molten metal is forced into the die cavity by hydraulic pressure acting against a plunger in the cylinder containing the metal.

Cold shut. A lapping of partially solidified metal that may occur in the formation of die castings and that constitutes an imperfection on or near the surface of the casting.

Cold work. Plastic deformation at normal temperatures, and at such rates that substantial increases occur in the strength and hardness of the metal. Visible structural changes include changes in grain shape and, in some instances, mechanical twinning or banding.

Colloid. A mixture of a liquid and solids whose separate particles have a limited size range of from 5 to 100 $m\mu$. In general, colloidal solutions do not settle out on standing unless some reaction first occurs.

Columnar structure. A coarse structure of parallel columns of grains, which is caused by highly directional solidification resulting from sharp thermal gradients.

Combination die. A die having two or more cavities for dissimilar parts.

Constituent. A characteristic structure of an alloying element or intermetallic compound that usually may be recognized under the microscope.

Constituent network. Soluble or insoluble constituents that have formed a dendritic network and have thus destroyed the normal continuity of the polycrystalline structure.

Constitutional diagram. A diagram representing the proper conception of the various changes that take place during solidification of an alloy because it relates the heat changes to phase change.

Contraction. The change in volume as metal cools from the liquid to the solid state. May also refer to the diminishing size of a metal part upon cooling from a high to a lower temperature.

Core pin. A core, usually of circular section, but having some draft.

Core plate. A plate used to actuate core pins.

Creep. The flow or plastic deformation of metals held for long periods of time at stresses lower than the normal yield strength. The effect is particularly important if the temperature of stressing is in the vicinity of the recrystallization temperature of the metal.

Crystals. Crystals are characterized by the fact that the atoms of which they are built are rigidly arranged in space according to a definite geometrical pattern, which for most metals and alloys is cubic.

Damping capacity. The ability of a metal to absorb vibrations, changing the mechanical energy into heat.

Dendrite. A crystal formed by solidification and characterized by a tree-like pattern composed of many branches; also termed *pine-tree* and *fir-tree* crystal.

Diamagnetic. A material that has less magnetic permeability than a vacuum. The material would be repelled weakly by a magnet.

Dimensional stability. Ability of alloy to remain unchanged in size or shape after aging.

Dowel pin. A guide pin to ensure registry between two die sections.

Draft. The amount of taper in the side walls of die impressions; or the taper given to the sides of a pattern to enable it to be withdrawn easily from the mold.

Dross. The product of oxidation of most molten metals.

Ductility. The property that permits permanent deformation before fracture by stress in tension.

Ejector marks. Marks left on castings by ejector pins.

Ejector pins. Pins used to eject castings from a die.

Ejector plate. Plate used to actuate ejector pins.

Eutectic. 1. The isothermal reversible reaction of a liquid that forms two different solid phases in a binary alloy system during cooling. 2. The alloy composition that freezes at constant temperature, undergoing the eutectic reaction completely. 3. The alloy structure of two or more solid phases formed from the liquid eutectically.

Eutectic temperature. The lowest melting temperature in a series of mixtures of two or more components.

Exfoliation. A type of corrosion that progresses parallel to the outer surface of the metal, causing layers of the metal to be elevated by the formation of corrosion products.

Extensometer. Device, usually mechanical, for indicating the deformation of metal when it is subjected to stress.

Extrusion. Shaping metal into a chosen continuous form by forcing it through a die of appropriate shape.

Fatigue. The tendency for a metal to break under conditions of repeated cyclic stressing considerably below the ultimate tensile strength.

Ferrite. A solid solution in which alpha iron is the solvent, and which is characterized by a body-centered cubic crystalline structure.

Fillet. The concave curved junction of two surfaces that would otherwise meet at an angle.

Flakes. Internal fissures in ferrous metals. In a fractured surface these fissures may appear as sizable areas of silvery brightness and coarse textures; in wrought products such fissures may appear as short discontinuities on an etched section.

Flame-hardening. A process of hardening a ferrous alloy by heating it above the transformation range by means of a high-temperature flame and then cooling as required.

Flow lines. Lines appearing on the as-cast surface of the casting or on a machined surface; such lines show the manner in which the molten metal flowed.

Fluidity. The ability of a liquid metal to flow readily, as measured by the length of a standard spiral casting.

Flux. A powdered solid or gas that is used to degas or remove oxides and other undesirable materials from molten metal.

Fluxing tube. A cast-iron or refractory tube that is used to introduce gaseous flux into molten metal.

Furnace lining. Refractory lining of melting or combustion chamber of furnace.

Furnace shell. The outside steel sheath of a furnace.

Fusion point. The temperature reached in the heating of foundry sand or clay at which the material no longer holds its shape, due to its softening under heat.

Galling. The removal of particles from localized areas; caused by sliding friction between mating members.

Galvanic corrosion. Electrochemical corrosion that results from exposure of an assembly of dissimilar metals in contact or coupled with one

another; or of a metal containing macroscopic or microscopic areas dissimilar in composition or structure.

Gate. Passage connecting a runner with a die cavity. Also, the entire ejected contents of a die, including the casting or castings and the gates, runners, sprue (or slug), and flash.

Gooseneck. The pressure vessel or metal-injection pump in an air-injection casting machine.

Grain refiner. Any alloy or substance that is added to molten metal to refine the grain structure or to produce small grains in the castings.

Grain size. In many nonferrous metals, particularly alpha brasses, grain size is expressed in millimeters average diameter and is determined by comparison with standards at 75 diameters in magnification. The grain size may also be expressed in terms of the number of grains per unit area or volume.

Hardener. A preliminary alloy, of composition high in one or more alloying elements, which is added in making a melt and which permits closer control of composition than is possible with the addition of the pure metals. Also referred to as *rich alloy* or *master alloy*.

Hard spots. Dense inclusion in a casting; commonly oxides which are harder than the surrounding metal.

Hardware finish. An especially smooth, as-cast finish that requires a minimum of preparation for plating.

Heat. A stated weight of metal obtained from a period of continuous melting in a furnace, or the melting period required to handle this weight. Also refers to a complete furnace load of castings being heat-treated.

Heat checking. Crazing of a die surface, especially when subjected to alternate heating and cooling by molten metal. The fine cracks resulting produce corresponding veins on castings.

Heel. Small amount of molten metal remaining in melting furnace before charging ingot or other solid material.

Heterogeneous structure. A metallic structure with more than one phase.

Hob. A block or punch having the shape of, and used to produce, a die cavity by forcing it into a die block.

Holding furnace. Furnace used for holding molten metal preparatory to pouring castings.

Hot cracking. A weakness of some cast alloys at temperatures just below the solidifying point.

Hot-short. Brittle or lacking strength at elevated temperatures.

Impression. Cavity in a die.

Inclusion. A foreign material, such as oxide particles, oxide film, or refractory particles, that is entrapped in the casting during solidification.

Induction furnace. Furnace heated by resistance of metal to flow of flux lines induced by alternating electric current.

Ingot. A pig or slab of metal.

Inhibitor. 1. A material such as fluoride, boric acid, or sulfur used to inhibit the burning of molten magnesium alloys. 2. An agent added to pickling or other solutions to minimize corrosion.

Injection. The act or process of forcing molten metal into a die.

Insert. A piece of material, usually metal, set in the die.

Insoluble constituent. A constituent that is virtually insoluble in its parent matrix at all temperatures below the solidus.

Intergranular corrosion. A type of electrochemical corrosion that sometimes occurs in as-cast alloys or alloys that have had very little working. The attack progresses preferentially through areas around the dendrites and dendritic arms, as a result of composition gradients.

Intermetallic compound. A compound of two or more metals that has a characteristic crystalline structure and may have a definite composition or a range of compositions corresponding to a solid solution.

Killed steel. Steel deoxidized with a strong deoxidizing agent such as silicon or aluminum to reduce the oxygen content to a minimum so that no reaction occurs between carbon and oxygen during solidification.

Ladle. Receptacle for the transfer of metal.

Laminations. Defects resulting from the presence of blisters, seams, or foreign inclusions aligned parallel to the worked surface of a metal.

Leak. A discontinuity in a casting that permits the passage of a gas or a fluid through a wall which is designed to prevent such passage. Leaks usually are caused by oxide films, inclusions, or shrinkage.

Liquidus. A line on a binary phase diagram or a surface on a ternary phase diagram, representing the temperatures at which freezing begins during cooling, or melting ends during heating, under equilibrium conditions.

Locating points. Pins used to obtain correct register when machining castings.

Locking device. Mechanical equipment that locks the mold together to guard against separation of the mold.

Loose piece. A core positioned by, but not fastened to, a die, and so arranged as to be ejected with the casting.

Macroscopic. Visible either with the naked eye or under low magnification (as great as about 10 diameters).

Martempering. The process of quenching an austenitized ferrous alloy at a temperature in the upper portion of the temperature range of martensite formation, or slightly above that range, and holding it in the quenching medium until the temperature throughout the alloy is substantially uniform. The alloy is then allowed to cool in air through the temperature range of martensite formation.

Martensite. An unstable constituent in quenched steel, formed without diffusion and only during cooling below a certain temperature known as M_s temperature. The structure is characterized by its acicular appearance on the surface of a polished and etched specimen.

Matrix. The principal metallurgical phase in which another constituent is embedded.

Mechanical properties. Properties that define the behavior of metals under stress: yield strength, ultimate strength, elongation, hardness, shearing strength, endurance limit, and density.

Melting loss. Loss of metal in the charge during the melting operation.

Melting range. The range of temperature in which an alloy melts, that is, the range between solidus and liquidus temperatures.

Melting rate. Weight of metal melted in a specific time interval.

Metallography. The science concerning the constitution and structure of metals and alloys as revealed by the microscope.

Metal saver. A core employed primarily to reduce the amount of metal used in the casting and thus to avoid sections of excessive thickness.

Micrography. Study with a microscope of fine structure—individual crystals, their size, distribution, and composition.

Micron. A linear distance of 0.001 mm.

Microstructure. The general arrangement of crystals in solid metal as seen by the naked eye or at low magnification. The term is also applied to the general distribution of impurities in a mass of metal as seen by the naked eye after etching.

Modulus of elasticity. The slope of the elastic portion of the stress-strain curve in mechanical testing; the stress divided by the unit elongation.

Modulus of rigidity. The ratio of the unit shear stress to the displacement caused by it per unit length in the elastic range.

Modulus of rupture. The ultimate strength or the breaking load per unit area of a specimen tested in torsion or in bending.

Multiple-cavity die. A die having a number of duplicate impressions.

Neutral refractory. A refractory material that is neither definitely acid nor definitely basic. However, the term is merely relative in most cases, since at high temperature such a material will usually react chemically with a strong base, functioning as a weak acid; or with a strong acid, functioning as a weak base. Chrome refractories are the most nearly neutral of all commonly used refractory materials.

Nitriding. A process of case-hardening in which a ferrous alloy, usually of special composition, is heated in an atmosphere of ammonia or in contact with nitrogenous material to produce surface hardening by the absorption of nitrogen, without quenching.

Normalizing. A process in which a ferrous alloy is heated to a suitable temperature above the transformation range and is subsequently cooled in still air at room temperature.

Notch brittleness. Susceptibility of a material to brittleness in areas containing a groove, scratch, sharp fillet, or notch.

Nozzle. The outlet end of a gooseneck. Also, the fitting that joins the gooseneck to the sprue hole of the die.

Overflow well. A recess that is connected to the die cavity and functions as a vent.

Pallet. A shallow metal tray on which ingots are stacked.

Parting line. The mark left on the casting where the die halves meet. Also, the surface between the cover and ejector portions of the die.

Pearlite. The lamellar aggregate of ferrite and carbide.

Peritectic reaction. An isothermal reversible reaction in binary alloy systems, in which a solid and a liquid phase react during cooling to form a second solid phase.

Peritectoid reaction. An isothermal reversible reaction in binary alloy systems in which two solid phases react during cooling to form a new solid phase.

Permanent set. Inelastic deformation.

Phase diagram. A graphical representation of the equilibrium temperature and composition limits of phase fields and phase reactions in an alloy system. In a binary system, temperature is usually the ordinate and composition the abscissa. Ternary and more complex systems require several two-dimensional diagrams to show the temperature-composition variables completely. In metal systems, pressure is

usually considered constant, although it may be treated as an additional variable.

Photomicrograph. A photographic reproduction of any object magnified more than 10 diameters. The term *micrograph* may be used.

Pig. Masses of commercially pure metal or rich alloys cast to convenient forms and sizes from reduction hot metal and used as raw materials in the production of aluminum alloys.

Pinhole porosity. Small holes scattered through a casting, caused possibly by microshrinkage or gas evolution during solidification.

Plastic deformation. Permanent distortion of a material under the action of applied stresses.

Platen. Portion of a casting machine against which die sections are fastened, or of presses against which dies are fastened.

Plunger. Piston that forces molten metal into a die.

Plunger machines. Die-casting machines having a plunger in continuous contact with molten metal.

Porosity. Voids or pores, such as result from air trapped in a casting.

Port. Opening through which molten metal enters the injection cylinder of a plunger machine or is ladled into the injection cylinder of a cold-chamber machine.

Pot wash. A refractory base used to support crucibles in melting or holding furnaces.

Pouring slot. Port through which molten metal is ladled into the cold-chamber of a casting machine.

Proof stress. In a test, stress that will cause a specified permanent deformation—usually 0.01 per cent or less—in a material.

Proportional limit. The greatest stress that the material is capable of sustaining without a deviation from the law of proportionality of stress to strain (Hooke's law).

Pyrometallurgy. Process metallurgical operations employing heat, such as roasting and smelting.

Radiograph. The impression made on a sensitive film or plate by X rays.

Red-shortness. Brittleness in steel when it is red hot.

Refractories. Substances that are able to resist high temperature and so can be used for linings of furnaces and ladles, production of crucibles, and preparation of molds and other articles required in foundry practice. While their primary function is resistance to high tempera-

ture, they may be called upon to resist abrasion, corrosion by slags or other fluxes, or rapid changes in temperature.

Residual stress. Macroscopic stresses that are set up within a metal as the result of nonuniform plastic deformation. This deformation may be caused by cold working or by drastic gradients of temperature from quenching or welding.

Reverberatory furnace. A furnace having a vaulted ceiling that throws back the flame and heat toward the hearth of the upper surface of the charge to be melted.

Rimmed steel. An incomplete deoxidized steel normally containing less than 0.25 per cent carbon and having the following characteristics: (1) During solidification an evolution of gas occurs sufficient to maintain a liquid ingot top until a side and bottom rim of substantial thickness has formed (if the rimming action is intentionally stopped shortly after the mold is filled, the product is termed *capped steel*). (2) After complete solidification, the ingot consists of two distinct zones: a rim somewhat purer than when poured and a core containing scattered blowholes, a minimum amount of pipe, and an average percentage of metalloids somewhat higher than when poured and markedly higher in the upper portion of the ingot.

Runner. A die passage connecting the sprue hole, or plunger hole, of a die to the gate where molten metal enters the cavity.

Salt-spray test. An accelerated corrosion test in which the metal specimens are exposed to a fine mist of salt-water solution.

Season cracking. A term used in the copper industry for stress-corrosion cracking that involves only residual stresses and specific corrosive agents, usually ammonia or compounds of ammonia.

Segregation. Concentration of alloying elements at specific regions, usually as a result of the primary crystallization of one phase with the subsequent concentration of other elements in the remaining liquid. *Microsegregation* refers to normal segregation on a microscopic scale whereby material richer in alloying element freezes in successive layers on the dendrites and in the constituent network. *Macrosegregation* refers to gross differences in concentration; it may be normal, inverse, or gravity segregation.

Seizing. Damaging of a metal surface by rubbing with another metal surface.

Semipermanent mold. A permanent mold in which sand cores are used.

Shot. That portion of the casting cycle in which molten metal is forced into the die.

Shrink. A cavity of dentritic shape caused by inadequate feeding.

Shrinkage porosity. A porous condition in a casting section caused by improper feeding of that section. The occurrence of a porous condition rather than a shrink hole seems to be dependent upon the amount of dissolved gas in the metal.

Shrink mark. A surface depression that sometimes occurs adjacent to a thick section that cools more slowly than adjacent sections.

Slag. A product resulting from the action of a flux on the nonmetallic constituents of a processed ore, or on the oxidized metallic constituents that are undesirable. Usually slags consist of combinations of acid oxides with basic oxides, and neutral oxides are added to aid fusibility.

Slide. Portion of a die, generally arranged to move parallel to the parting, the inner end of which forms a part of the die cavity wall; contains one or more undercuts, and sometimes includes a core or cores.

Slip. A process of plastic deformation by the irreversible shear displacement of one part of a metal crystal relative to another, in a definite crystallographic direction and usually on a specific crystallographic plane.

Slip bands. A series of parallel lines produced across a crystal grain by deforming the body after polishing the surface on which the lines appear.

Slug. Excess metal left at the end of the injection cylinder of a cold-chamber machine after injection is completed.

Slush casting. A casting made of an alloy that has a low melting point and freezes within a wide range of temperature. The metal is poured into the mold and brought into contact with all surfaces to form an inner shell of frozen metal; then the excess metal is poured out. Castings that consist of completely enclosed shells may be made by using a definite quantity of metal and a closed mold.

Smelting. A metallurgical thermal processing operation in which the metal or matte is separated in fused form from nonmetallic materials or other undesired metals with which it is associated.

Soaking. Prolonged heating of a metal at a selected temperature.

Soldering. Sticking or adhering of metal to portions of the die.

Solidification. Change from a liquid to a solid state. The cooling of a mass of metal goes on progressively from the outside to the center. First an outside skim of crystals forms at the mold face, and as the metal cools other crystals solidify and attach themselves to the outer layer of crystals, and so the dendrites grow inward until all the interior

is solid. Pure metals solidify always at one temperature, alloys frequently do not.

Solidification shrinkage. The decrease in size accompanying the freezing of a molten metal.

Solidus line. A line on a binary phase diagram, or a surface on a ternary phrase diagram, representing the temperatures at which freezing ends during cooling, or melting begins during heating, under equilibrium conditions.

Soluble constituent. A constituent which, at a temperature below the solidus, becomes partially or totally soluble in the matrix of the parent phase.

Solution heat-treatment. A process in which an alloy is heated to a suitable temperature, is held at this temperature long enough to allow a certain constituent to enter into solid solution, and is then cooled rapidly to hold the constituent in solution. The metal is left in a supersaturated, unstable state and may subsequently exhibit age hardening.

Solvent. The base metal or major constituent in a solution.

Sorbite. Tempered martensite that has a microstructure of distinctly granular appearance. Further tempering causes the appearance of clearly resolvable carbide particles.

Spalling. The cracking and flaking of metal particles from a surface.

Spelter. Crude zinc obtained by smelting.

Split gate. A gate having the sprue axis in the die parting.

Sprue. Metal that fills the sprue hole which connects the nozzle with runners.

Sprue pin. A tapered pin with rounded end projecting into a sprue hole; acts as a core and deflects the metal, and aids in the removal of the sprue.

Strain. Deformation expressed as a pure number or ratio.

Stress. The load per unit of area. Ordinarily stress-strain curves do not show the true stress (load divided by area at that moment) but a fictitious value obtained by using always the original area.

Stringer. A microstructural configuration of alloy constituents or foreign material lined up in the direction of working.

Stripping. Removing coated or electrolytically deposited metal or oxides from the base metal.

Sulfur dome. An inverted container holding a high concentration of sulfur dioxide; used over a pot of molten magnesium in connection with the die casting of magnesium.

Supersonic Reflectoscope. Instrument made by the Sperry Corporation to test the soundness of a metal ingot or part by comparing reflection of high-frequency sound waves with reflection from a sample of known quality.

Tarnish. Surface discoloration on a metal, usually from a thin film of oxide or sulfide.

Tempering. A process of reheating quench-hardened or normalized steel to a temperature below the transformation range, and then cooling at any rate desired.

Thermal analysis. The determination of equilibrium conditions and phase relationships in metals by means of thermal arrests shown on heating and cooling curves.

Thermocouple. An instrument having two dissimilar metals in contact, the junction of which gives rise to a measurable electrical potential with changes in temperature.

Throwing power. The ability of an electroplating solution to deposit metal uniformly on a cathode of irregular shape.

Tie rod. A bar used in a casting machine to hold dies against pressure; also serves as a way along which the movable die platen slides.

Toggle. Linkage in a casting machine employed to multiply pressure mechanically in locking the dies. Also, linkage used for core locking and withdrawal in a die.

Transfer ladle. A ladle supported on a monorail or carried in a shank that is used to transfer metal from the melting furnace to the holding furnace.

Transition point. The temperature of transformation of a substance from one solid crystalline form to another.

Trim die. Die for shearing or shaving flash from a casting.

Troostite. Tempered martensite that etches rapidly, usually appears dark, and is not resolved by the microscope.

Undercut. A recess in the side wall or cored hole of a casting, so disposed that a slide or special form of core is required to permit ejection of the casting from the die.

Unit die. A die interchangeable with others in a common holder for individual dies.

Vent. A narrow passage, usually at the die parting, that allows air to escape from the die cavity as it is filled with metal.

Virgin metal. Metal obtained directly from ore and not used before.

Volatility. The tendency of a substance to vaporize at the temperature under consideration.

Water line. A tube or passage through which water is circulated to cool a casting die.

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